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Trend surface analysis as an aid in exploration for Mississippi Valley type ore deposits

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TREND SURFACE ANALYSIS AS AN AID IN

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ABSTRACT

The conditions necessary for emplacement of Mississippi Valley-type mineral deposits can be expressed using mathematical symbols as a function of the pre-depositional topography of the host formation and post-depositional structure. These conditions can be observed and analyzed in the Missouri region from residual maps of trend surface analysis of the Precambrian surface. In areas where the topography, prior to deposition of the ore bearing horizon, has been strongly altered by the deposition of the basal Paleozoic formation, the Lamotte Formation, residual maps from trend surface analysis of the top of the Lamotte better illustrate these conditions.

The Lamotte Formation in Missouri can be divided into five units. The characteristics of the formation vary upward from a basal arkose association through an unconformity sand association to a blanket sand association. The contact between the Lamotte and overlying Bonneterre Formation is generally conformable and gradational, although in certain areas this contact may be unconformable. The character of the basal Bonneterre transition zone is strongly influenced by the proximity of Precambrian topographic highs. Some of the sand in the basal Bonneterre may have been derived from preexisting Lamotte.

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I. INTRODUCTION

The occurrences of mineral deposits are dependent on many factors, but certain general characteristics of Mississippi Valley-type mineralization remain constant. These deposits are stratiform in character with the ore concentration within a single or a few formations. The ore bodies occur in shallow water marine carbonates and are contained in stratigraphic traps, organic reefs, or in breccias of various origin. Veins may be associated with these ore bodies. The main features marking coincidence of occurrence are as follows:

(1) They are peripheral to known topographic highs on the Precambrian erosional surface.

(2) They occur chiefly where the basal Paleozoic formations pinch out on Precambrian topographic highs indicating that these highs were also highs during the early Paleozoic.

(3) They are overlain by shales which have acted to "trap" the ore deposits.

(4) They are associated with the dolomitization of algal reefs and/or with faults and fractures with brecciation along these zones appearing to be the major type of ground preparation.

(5) Very commonly, there is a spatial relationship between the mineral deposits and the limestone-

dolomite interface.

These conditions may be expressed in mathematical symbols as:

$$Md = f\ (PcH + Po + Sc + Fg + Rl_d + X) \qquad 1\text{-}1$$

where Md = Mineral deposits

PcH = Precambrian highs

Po = Pinchouts

Sc = Shale caps

Fg = Favorable ground preparation

Rl_d = Relationship to limestone-dolomite interface

X = Other local and/or unknown conditions

There is a natural tendency to separate structure and stratigraphy into separate disciplines, ignoring the concept that preexisting structures are a major factor in determining stratigraphic environments. It is apparent that the shale caps, the pinchouts, the dolomitization of algal reefs, and the relationship of mineral deposits to the limestone-dolomite interface are a function of the preexisting topography as are the Precambrian highs. Formula 1-1 may be rewritten:

$$Md = f\ (Pt + Ps + X) \qquad 1\text{-}2$$

where Md = Mineral deposits

Pt = Preexisting topography

Ps = Post depositional, pre-mineral, structure (faulting, fracturing, slumping with brecciation)

X = Other local and/or unknown conditions

Trend surface analysis is a mathematical procedure whereby a surface can be separated into two component parts, the trend surface and the residuals. The deviations around the mean of the input data are equal to the deviations due to regression (the trend surface) plus the deviations from regression (the residuals). In structural analysis, the trend surface defines and isolates the large scale regional features and the residuals represent local variations superimposed upon the regional trend.

Geological sources of residuals may be local variations of the surface which were present before the surface was warped by diastrophism (preexisting topography) or small scale folding and faulting which also do not enter into the regional trend. While in theory it is possible to completely remove the regional trend with a very high order trend surface, this is impractical and the contribution of the regional trend to the residual must be considered, especially on low order surfaces. If it were possible to remove the regional trend this relationship could be written:

$$R = f\ (Pt + Ps) \qquad 1\text{-}3$$

where R = Residual value

Pt = Preexisting topography

Ps = Post depositional local structure

Formula 1-3 can be substituted into Formula 1-2, and, if it is assumed that all post depositional local structure is pre-mineral, then the following relationship is obtained:

$$Md = f\ (R + X) \qquad 1\text{-}4$$

where Md = Mineral deposits

R = Residuals

X = Other local and/or unknown conditions

The mathematical expression states that structural and stratigraphic conditions necessary for the formation of a Mississippi Valley-type mineral deposit may be defined by the examination of residuals from a trend surface analysis of the structural surface below the host formation. Care must be used however as the structural conditions may be in part post-ore deposition.

If this concept is valid, the question then arises with respect to which surface should be subjected to analysis. It would be desirable to pick a surface directly below the potential ore horizon. In the southeastern Missouri district, the main mineralization is concentrated in the Bonneterre Formation and occasionally, the upper horizons of the underlying Lamotte. Therefore, a trend surface analysis of the Precambrian surface should illustrate the relationship between mineral districts and residuals from the computed regional trends. In areas where the surface configuration has been strongly changed due to deposition of the Lamotte Sandstone, the relationship should be illustrated by the residuals from trend surface analysis of the top of the Lamotte.

Early in the study it was observed that the Lamotte-Bonneterre contact chosen from well logs did not define a consistent datum horizon. It was necessary, therefore, to conduct a stratigraphic study of the Lamotte Formation to establish a consistant datum horizon upon which to base the trend analysis.

The major part of this investigation has been conducted within the geographic boundaries of Missouri. However, since additional information was available from adjoining states, an arbitrary limiting boundary was defined as illustrated in Figure 1.

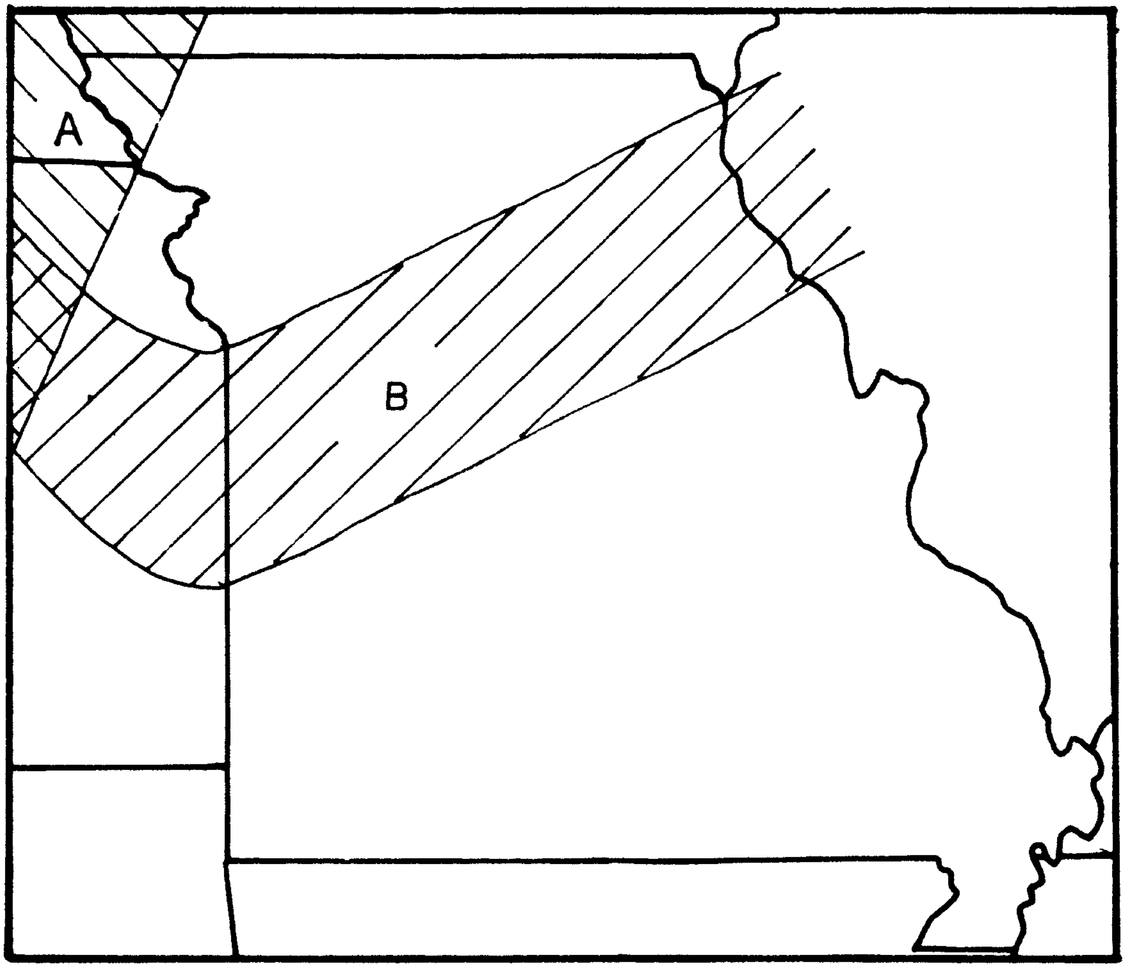
Figure 1. Index map illustrating study area.

II. REVIEW OF PREVIOUS INVESTIGATIONS

A. Precambrian Surface

Snyder (1968a, 1968b) gave a general tectonic history of the Midcontinent Region and described the main positive and negative structural elements he recognized. In the discussion of Precambrian history of this region, Snyder showed an extension of the Keeweenawan Basin of late Precambrian age and a metamorphic belt extending across Missouri (Fig. 2). The work of King and Zietz (1971) on the Midcontinent gravity high appears to confirm the existence of this Keeweenawan extension since this gravity high can be traced from Michigan through Kansas. E. Kisvarsanyi (personal communication, 1971) suggests, however, that this metamorphic belt may not exist since it is not verified by more recent well samples she has examined.

Snyder (1968a, 1968b) also described a belt of volcanics extending from western Ohio through southeast Missouri to northwest Oklahoma. In Missouri this belt is expressed as the St. Francois Mountains and the Eminence area. Local relief on the surface of this belt of volcanics is over 2,000 feet and according to Snyder (1968a, 1968b) this belt formed a continental divide through late Precambrian and early Paleozoic time. Snyder also listed a series of early structural features which had a direct bearing on early Paleozoic en-



A = Limit of Keeweenawan Basin
B = Precambrian metamorphic belt

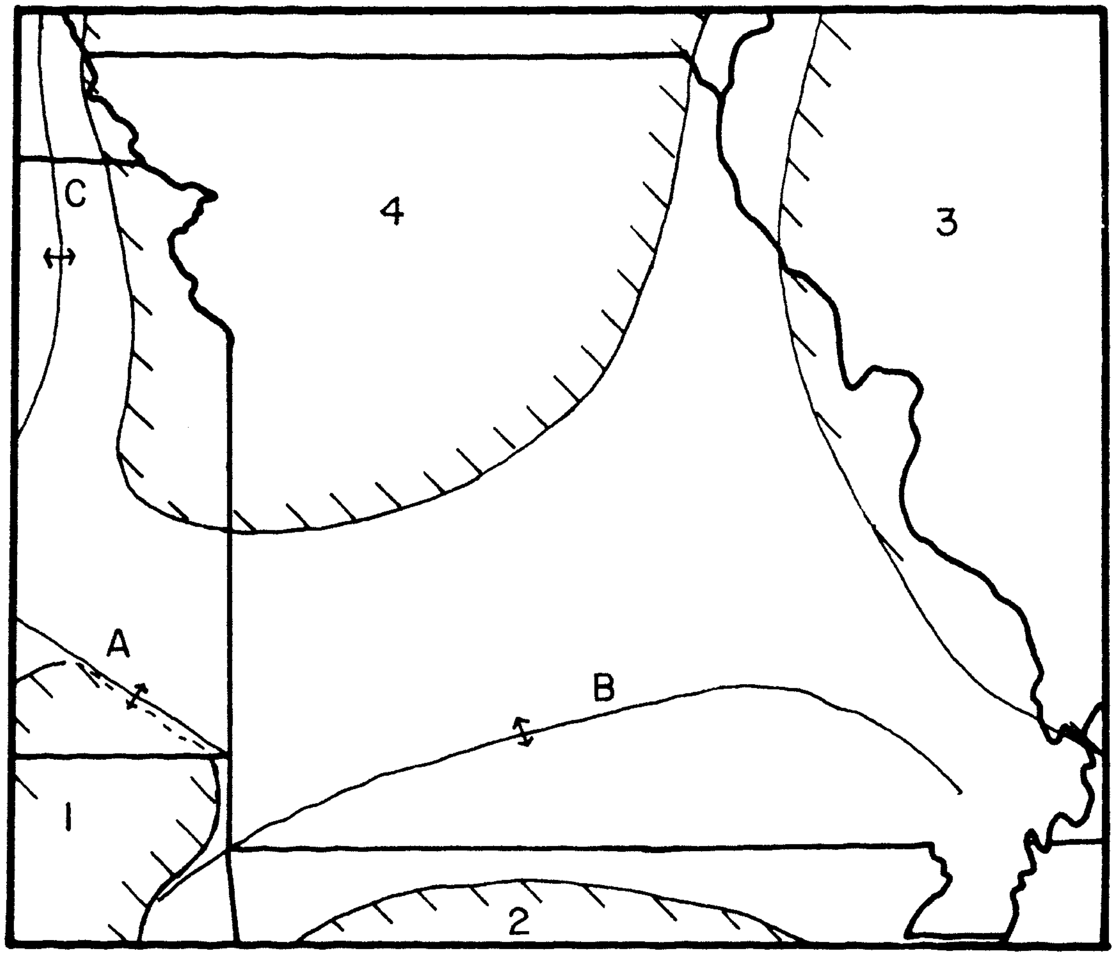
Figure 2. Approximate outlines of Keeweenawan Basin and Precambrian metamorphic belt (modified from Snyder, 1968a, 1968b).

vironments of deposition within the area of study (Fig. 3).

Grenia (1960) mapped the Precambrian basement topography and described the principle rock types found in many areas of the state. The structural map of Missouri and accompanying text by McCracken (1971) list in detail the main structures throughout the state. Cole (1962) contoured the Precambrian surface of Kansas and delineated some of the larger structural elements. Denison (1966) suggested uplift of the Precambrian surface prior to deposition of Paleozoic sediment along certain axes, for example, the Nemaha Ridge, to allow for the present distribution of the early Paleozoic sediments. Hager (1949) had carried this line of reasoning even further by suggesting that the lines or belts of weakness in older rocks may furnish the lines or belts of weakness which later forces affect.

B. Mineral Districts

The main mineral districts in the area of study have been the subject of numerous papers. Of main concern in this study are those papers describing Mississippi Valley-type deposits. These deposits with their type locality in the Mid-continent United States are, perhaps, best characterized by the Upper Mississippi Valley, the Tri-State, and the south-eastern Missouri districts. Snyder (1968a) attempted to describe these deposits as being stratiform in character, occurring within a single or few formations, although similar sulfides may occur in all formations above and below the



<u>NEGATIVE FEATURES</u>

1 = Cherokee Basin
2 = Arkansas Basin
3 = Illinois Basin
4 = Forest City Basin

<u>POSITIVE FEATURES</u>

A = Chautauqua Uplift
B = Ozark Uplift
C = Nemaha Ridge

Figure 3. Early structural features in area of study (modified from Snyder, 1968a, 1968b).

major deposits. He further states that the ore bodies are found in shallow water marine carbonates and these bodies occur at the rim of a sedimentary basin or over highs within the basin and are normally near the limestone-dolomite interface. The ore minerals are normally simple sulfides of zinc, lead, and copper, but barium, fluorine, cobalt, nickel, cadmium, germanium, and silver may be present. These mineral deposits can occur at any depth as, for example, the sphalerite mineralization in western Kansas at depths of from 4,900 to 6,440 feet (Snyder, 1968a).

Brockie, Hare, and Dinges (1968) summarized the characteristics of mineral deposition in the Tri-state district. In this report they show the main deposits normally are restricted to the horizon referred to as the "Boone Formation" which is composed of Meramecian and Osagean Mississippian cherty limestone. These Mississippian deposits normally are overlain by the Pennsylvanian Cherokee Shale which generally has been regarded as having acted as an impermeable barrier to rising mineral solutions. McKnight and Fisher (1970) in their summary of the Picher Field also stress the importance of the underlying Chattanooga Shale. Where this shale is absent due to removal by erosion, the Mississippian formations commonly contain some indication of mineralization. Where the Chattanooga Shale still is present, minor mineralization commonly is present scattered through the underlying Ordovician rocks in noncommercial amounts. Brockie, Hare, and Dinges (1968) describe three forms of ore bodies in the Tri-state district; the long narrow "runs", the circular "runs", and the flat lying "sheet ground" deposits. The run deposits appear to have a coincidence relationship with curved fracture patterns which surround dolomite cores.

According to Brockie, Hare, and Dinges (1968) recent deep drilling in the Tri-state district shows the Precambrian surface is very irregular with depths below the surface ranging from 290 to 2,000 feet.

The central Missouri district contains many small deposits of lead, zinc, and barite. According to Snyder (1968a), deposits are found in several lower Ordovician formations and may extend up to the Pennsylvanian sediments, but most are restricted to the Jefferson City Dolomite. The deposits are of two main types; sink deposits in which the ore occurs in brecciated rock around the outer margins of the central subsided zone and fracture fillings forming veins as much as several feet thick. The structure throughout this area is quite simple. The beds dip gently northwestward and are flexed by several northwestward trending anticlines and synclines. The largest fold is the Proctor Anticline. Many of the mineral deposits lie along the crests of the major anticlines and in particular the Proctor Anticline, while the other deposits normally are found on the gentle northeast flank of the Proctor and other anticlines (Mineral and Water Resources of Missouri, 1967).

The southeastern Missouri district, one of the world's largest lead mining districts, is composed of at least four major subdistricts and several minor subdistricts. Ore deposits throughout this district are stratiform and normally are in the Cambrian Bonneterre Formation although in areas mineralization may extend into the underlying Lamotte Sandstone. The ore bodies within this district take many different shapes and forms and usually are controlled by some sedimentary feature or structure. According to Snyder and Gerdemann (1968) the most common sedimentary structures localizing ore deposits are pinchouts, ridge structures, bar-reef complexes, algal reef complexes, disconformities, and submarine slides. Almost every type of sedimentary feature which represents an interruption in the blanket type carbonate deposition can be an ore trap and the sizes of the ore bodies are almost entirely a function of the size of the individual structure.

Wertz (1971) noted three coincidence factors in the occurrence of various mining districts in southeastern Arizona which are comparable with the controlling factors noted previously for Mississippi Valley-type deposits. These factors included major fracture intersection, noses and embayments as observed in isopachs, and an observation from Harris (1960) that the fractures seem to be concentrated in those areas where the rate of change in dip or strike of the beds was greatest. Wertz suggests that the southeast Arizona mining district appears to be controlled by preexisting topography (to account for the noses and embayments in isopachs) and post depositional structures (fracture intersections and rate in change of strike and dip). Where these two factors have been superimposed to the right degree, a mineral district should occur.

C. The Lamotte Sandstone

Ojakangas (1960, 1963) has given the most complete description of the Lamotte Sandstone in Missouri. He considered the Lamotte a time transgression facies equivalent to the Reagan Sandstone of Kansas, Oklahoma and Nebraska and the Mt. Simon Sandstone of Iowa, Illinois, Minnesota and Wisconsin. From cross-bedding and heavy mineral studies, he concluded the Lamotte had two main source areas; a small local area around the St. Francois Mountains and other local highs and the other, an undefined region to the north most probably the Hinckly Sandstone or the Bayfield Group.

In his discussion of the contact between the Lamotte and the overlying Bonneterre Formation, Ojakangas (1960, 1963) noted a transition zone of sandy dolomite between them. This zone is described as being over 200 feet thick near the center of the St. Francois Mountains, thinning to a six-inch horizon thirty miles to the northeast. The actual location of the contact was not defined by Ojakangas as he appeared to feel the exact placement of the contact was of little practical importance.

Other investigators, for example James (1951), also have noted the apparent gradational character of the contact. Most have called the contact completely conformable although Weller and St. Claire (1928) postulated a local unconformity between the two formations. The glauconitic character of the transition zone has been described by most authors, Ojakangas (1960), and is generally placed within the Lamotte. Lockman (1940), however, recognized these sands and their glauconitic character and placed them in the basal Bonneterre.

D. Trend Surface Analysis

Trend surface analysis has received a large amount of attention from geologists in the past few years due to the availability of high speed computers. Appendix 3 presents an outline of the theory and procedures used in trend surface analysis. Most geological use of trend surface analysis has been with geochemical and petrographic data with relatively few studies concerned with structural analysis.

Harbaugh and Merriam (1964, 1968) gave an excellent description of the theory and use of trend surface analysis in geological work. The 1964 paper described in detail the fitting of trend surfaces to structural data throughout the state of Kansas and showed an example of a strong correlation between petroleum occurrences and the residuals from the trend surface of the structure. Stevenson (1969, 1970) also showed this correlation in Illinois with trend surface analysis of isopach data for the Ste. Genevieve Limestone. In this context Harbaugh (1964, 1968), Forgotson (1963), Wolfe (1962) and several other authors have suggested that trend surface analysis might be an aid in mineral exploration.

Several computer programs of trend surface analysis have been written and made available to the public, such as the program of Esler, Smith and Davies (1968), modified for use in this investigation at the University of Missouri - Rolla campus.

The numbering system used to designate wells in this paper, with the exception of wells with an O designation, is the same system used by the various state surveys. The O designation is an arbitrary numbering system used to designate those wells still considered confidential by the company from which they were obtained.

III. DESCRIPTION OF LAMOTTE IN MISSOURI

Cuttings and cores from over 200 wells were examined and the general description for many of these wells is listed in Appendix 2. Select groups of wells illustrating specific characteristics are described in Appendix 4. The following is a description of the Lamotte and the transition zone between the Lamotte and the overlying Bonneterre Formation and is a summary of the information presented in Appendices 2 and 4.

The Lamotte in Missouri can be informally divided into five units on the basis of varying lithological characteristics. These units may represent an aggregate thickness of over 400 feet as, for example, in parts of St. Francois County. The lower three units, Units C, D, and E can generally be described as a fair to poorly sorted, angular to subrounded quartz to subarkosic sandstone becoming arkosic toward the base. The subarkosic to arkosic nature of the sand along with the strong hematite staining and occasional pyritic shales, and its relationship with the underlying Precambrian erosional surface indicates a basal arkosic association grading upward into an unconformity sand association. The red hematite staining and hematite shales with the occasional pyritic shales point to an oxidizing environment with occasional reducing conditions. The relationship of the lower Lamotte to the Precambrian surface and the very abrupt lateral lithological variations with abundant granite material, especially in the basal unit, Unit E, indicate that the lithological characteristics of the lower Lamotte were strongly dependent on local available source material. Prior to the deposition of Unit C, many Precambrian knobs stood emergent above the depositional base and served to restrict circulation. As the depositional period of Unit C included the burial of many of the small knobs, the upper two units, A and B, subsequently were deposited in a less restricted environment. This change from a relatively restricted environment to an open sea environment is the major difference between the lower three units and upper two units.

The upper two units may be described as well sorted, rounded to subrounded, fine to medium grained quartz sandstone. The areal continuity, cross bedding, uniformity of grain size and relative clean nature of the units indicate a blanket sand association deposited in a relatively unrestricted open sea environment. Figures 4 and 5 present the relationship between the various units of the Lamotte and their relationship to the underlying Precambrian erosional surface and the overlying Bonneterre Formation.

A. Transition Zone

The character of the contact between the Lamotte and the overlying Bonneterre Formation varies in different parts of the state. The factor that appears to be dominant in determining the characteristics of this zone is the proximity of

Figure 4. Idealized cross section of Lamotte-Bonneterre stratigraphy away from St. Francois Mountains.

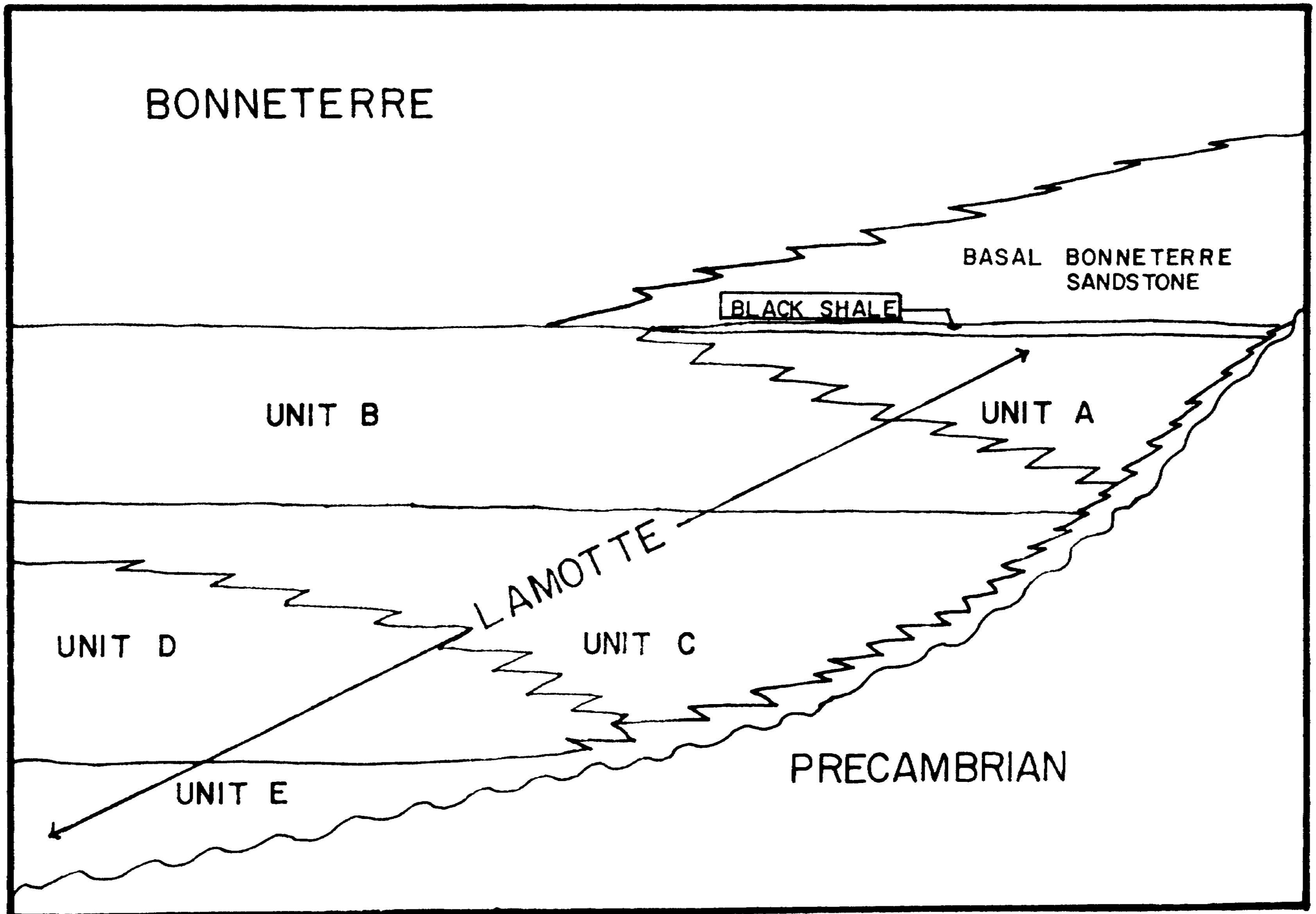

BONNETERRE
BASAL BONNETERRE SANDSTONE
BLACK SHALE
UNIT B
UNIT A
LAMOTTE
UNIT D
UNIT C
UNIT E
PRECAMBRIAN

Figure 4.

Figure 5. Idealized cross section of Lamotte-Bonneterre stratigraphy on west flank of St. Francois Mountains.

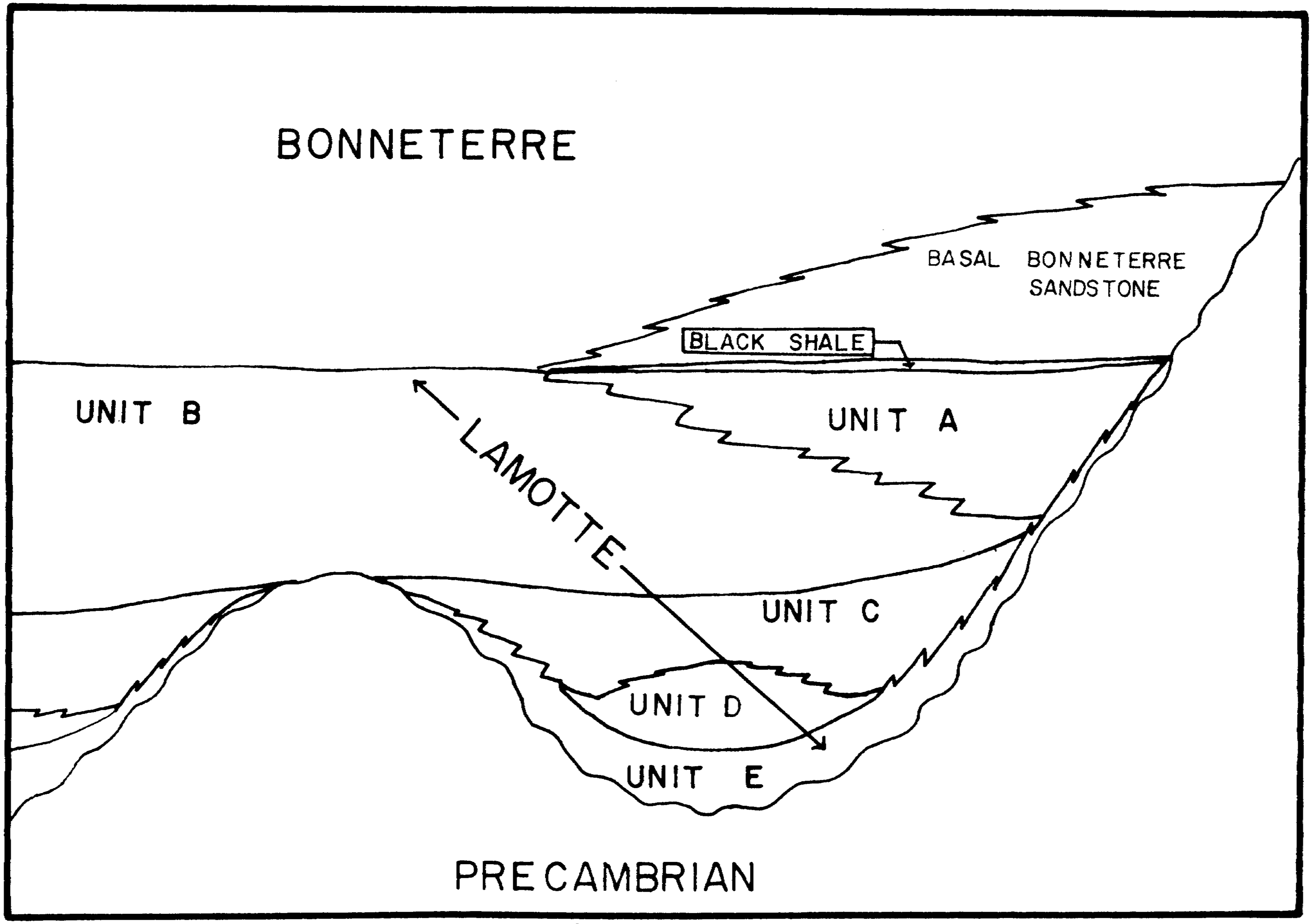

BONNETERRE
BASAL BONNETERRE SANDSTONE
BLACK SHALE
UNIT B
UNIT A
LAMOTTE
UNIT C
UNIT D
UNIT E
PRECAMBRIAN

Figure 5.

topographic highs on the Precambrian surface. In the vicinity of these highs, the contact normally is marked by a thin, black, pyritic shale band. Away from them, the contact generally is marked by a very thin transitional zone where the gray-buff Lamotte sand grades into basal Bonneterre.

The basal Bonneterre, in areas away from Precambrian highs, is a relatively pure dolomite. As Precambrian highs are approached, the basal Bonneterre becomes more argillaceous and arenaceous until it is almost a pure sandstone. The glauconitic content of this zone also varies greatly but appears to be highest a short distance away from known highs. The glauconite and shale content, to a certain extent, are correlated since the argillaceous carbonate zones are also usually very highly glauconitic.

The basal Bonneterre, in most regions, contains a small amount of quartz sand floating in the carbonate matrix. In many areas, especially on the northeast side of the St. Francois Mountains, the sand content of the lower Bonneterre increases to the point that this zone is, for all practical purposes, a pure quartz sandstone with carbonate cement and may easily be mistaken for Lamotte. The properties of the unit which allow it to be differentiated from the underlying Lamotte are outlined in Table I.

The color change can be the most reliable criterion; when the cores are wetted, the Lamotte generally remains about the same color while the Bonneterre usually becomes several shades darker. The thin, black shale which has been found only near known Precambrian highs is quite pyritic and appears to have been deposited in a strongly reducing environment. This shale band may be an indication of local unconformities. Serving as a break between two prominent sand units, it shows that between Lamotte and Bonneterre deposition, there was at least change in depositional pattern. It is likely that a large amount of sand found in the basal Bonneterre was derived from preexisting Lamotte. Figures 4 and 5 show the general relationships between the Lamotte and basal Bonneterre.

TABLE I

CRITERIA FOR SELECTION OF LAMOTTE-BONNETERRE CONTACT

	Lamotte	Bonneterre
Color dry	Buff to white (N7 to N8, light gray to very light gray to 5 YR 8/1 pinkish gray to 5 Y8/1 yellowish gray)	Gray - greenish if glauconite present (N4 to N6, medium light gray to medium dark gray)
Color wet	Approximately the same	Becomes several shades darker
Dolomite	None	Trace to predominant mineral
Glauconite	None	Trace to considerable
Phosphatic brachiopods	None	May be present
Undulations	None to few	None to many
Shale band	May be found at contact	
Sorting	Good	Fair to poor
Rounding	Subrounded	Subrounded to well rounded
Clay	Aside from pore space - absent	Trace to considerable amounts
Mica	May be present	Probably present

B. The Upper Lamotte

1. Unit A.--This unit is a quartz sandstone, buff to white, fine to medium grained, subrounded, and may show some crossbedding. The thickness of this unit varies from zero to 120 feet. The characteristic feature of this unit is the very open pore spaces. The area between the sand grains may contain small amounts of kaolin, but for the most part, no kaolin is present. This unit is best developed near the St. Francois Mountains.

2. Unit B.--This unit is, for all practical purposes, the same as the overlying Unit A except that the pore space has been filled in with kaolin. This unit is from 0 to 180 feet thick. Unit B is the most consistent and best developed unit in the Lamotte Formation.

Units A and B appear, for the most part, to be different facies members of the same larger unit with Unit A being the near-shore facies and Unit B its basinal equivalent (Fig. 4). The absence of kaolin in the pore space of Unit A probably is the result of deposition in a more active zone allowing the kaolin to be winnowed out and deposited farther basinward. As Units A and B sometimes are interbedded, this appears to reflect fluctuation in energy of deposition. The relatively clean nature of both Units A and B appears to reflect relatively open sea deposition with free circulation. In addition, Unit B forms the lowermost unit in the Lamotte in certain areas, for example, parts of Washington County and, for all practical purposes, the lowermost extent of Unit B appears to coincide with the uppermost extent of many small Precambrian knobs (Fig. 5). This seems to indicate this unit was deposited after the majority of pre-Lamotte valleys had been filled, in a more open sea environment. The kaolin in the interstitial spaces of the Lamotte was probably derived from the weathering and reworking of feldspar in the underlying granites.

C. The Lower Lamotte

1. Unit C.--This unit is a subrounded to subangular quartz sandstone which varies from 0 to 180 feet in thickness. The grain size of this unit normally shows a bimodal distribution with the two predominant sizes being .02 and .04 centimeters. The most prominent feature of this unit is the usually oily, red hematite stain covering all the particles. This stain is best developed near highs and appears to be less intense basinward. This unit probably was deposited in an oxidizing environment. Upon further investigation, it could probably be shown that the red stain is also a function of basement lithology with the stain being best developed near areas of relatively mafic Precambrian rock and less well developed to non-existing in areas of ultra-acidic rocks. Grains of feldspar are present in this unit and normally range from 2 to 5 per cent of the total volume. These grains are usually highly weathered and many times are almost completely kaolinized. The sorting of this unit is fair to poor.

2. Unit D.--This unit, a "cleaned up zone", has generally the same appearance as Unit C except that there is the absence of the oily red hematite stain. This unit is only found away from known Precambrian highs.

Unit D reaches maximum thickness away from highs. It appears that Units C and D are, for all practical purposes, facies equivalents with Unit D being the basinal equivalent of Unit C (Figs. 4 and 5).

3. Unit E.--This unit is a true basal arkose which ranges from 0 to 70 feet thick and is composed of material derived from reworking of the Precambrian regolith and incorporation of fresh Precambrian granitic material. Shaly beds are not uncommon.

This unit is best developed in the pre Lamotte basins and valleys, but it will usually persist up the side of valleys and knobs as a very thin zone. On the very tops of most knobs, this unit is normally absent (Figs. 4 and 5).

Two major source areas furnished material for the Lamotte. One, from exposed Precambrian outcrops, was a relatively important source during early Lamotte deposition but became important only in the general locale toward the end of Lamotte deposition. The other source area was to the north and the Precambrian clastics found in the Keeweenawan Basin extension to the east of the Nemaha Ridge are probably the remains of a much larger Precambrian clastic complex which furnished the majority of material for the Lamotte and probably also for its equivalent, the Mt. Simon Sandstone. As it is believed that the Nemaha Ridge was at least slightly positive during early Paleozoic, the area to the west in which the Reagan Sandstone was deposited probably had a different source. The Lamotte as defined in Kansas is a combination of Lamotte equivalent and basal Bonneterre.

In extreme southeast Missouri, the lack of available clastic materials allowed a Lamotte-equivalent carbonate sequence to be deposited. This area had been a negative area throughout the Mesozoic and Cenozoic. The Lamotte and Lamotte-equivalent sediment deposited in this area indicates a relatively deep water environment of deposition. This appears to suggest that the structural characteristics defined for this area during later geological periods were already set during the early Paleozoic.

IV. TREND SURFACE ANALYSIS OF PRECAMBRIAN SURFACE

Trend surface analysis is a process whereby trends, which may be lines, surfaces or four dimensional "hypersurfaces" can be recognized, isolated, and measured. In geology, this method can be used to separate regional variations, or trends, from local, small scale variations superimposed on the regional trend. Removal of the trend has the effect of isolating and emphasizing the local components. The trend surface is a mathematical surface, which, for the degree of equation used, is the best fitting representation of the surface.

To employ trend surface analysis, certain assumptions must be made. It is assumed that the independent variables, in this case the X and Y map coordinates, are measures without error and errors made in measuring the dependent variable Z, in this case the elevation of the Precambrian surface, are random variables with a normal distribution with a mean of zero and variation of σ^2.

Ideally, the data points should be equally distributed over the study area in trend surface analysis. Concentration of data points in a specific area tends to bias the trend or to result in a trend surface with weighted properties. Any resulting clustering will tend to remove the randomness of the errors in measuring Z. The theory and procedures used in trend surface analysis are discussed in Appendix 3.

A. Quality of Control

The validity of interpretations drawn from trend surface analysis also depends upon the quality and quantity of the data providing control for the area under study. Quality, however, is a subjective factor depending upon the capability of the investigator to provide geologically sound data for analysis. The most significant problems in quality control occurred where location coordinates or ground elevations for well logs were uncertain or inaccurate. When this occurred, data were rejected.

In a study such as this in which the data are derived from available drill records, the data tend to be clustered. To minimize possible bias in areas of abundant well data certain data points were eliminated by first observing which areas contained more than one possible control well per section. The data from these wells were then compared to determine if there was any reason to assume the data from one well were more useful or reliable than the others. If this could be determined, the best well was accepted and the rest rejected. If there was no reason to make this assumption, the well was selected by placing a grid over the section in question and selecting the control well through use of a table of random numbers. If the data spacing was still overly dense, in this case, if any township contained more than four control wells, a grid was superimposed over the entire area and again a random number table was used to eliminate points.

The use of this procedure provided for a certain reduction in the clustering of points but did not eliminate this problem. The study area was, therefore, subdivided into eight subareas (Fig. 6). The basis for the subdivision was the similarity of structural geology throughout the subarea. Table II lists the major geological structure in each area.

TABLE II

MAIN STRUCTURAL FEATURES IN DIVISIONS OF AREA OF STUDY

Subarea 1	The Nemaha Ridge
Subarea 2	The Forest City Basin
Subarea 3	Prominent northwest trending faults
Subarea 4	Series of crossing northwest and northeast fold and fault systems, i.e. Chautauqua Upwarp, Seneca Trough, Bendelari Trough, Miami Trough, Picher Anticline
Subarea 5	Strongly negative area - the Arkansas Basin, Illinois Basin, and Mississippi Embayment
Subarea 6	The St. Francois Mountains
Subarea 7	Northwest trending structural lineament
Subarea 8	General inflection zone between Forest City and Illinois Basins

The density of data points was then calculated to establish a measure of relative control in each subarea. These results can be seen in Table III.

As can be seen from the table, although the data points are generally evenly distributed over the subareas, Area 1,

Figure 6. Subdivisions of study area

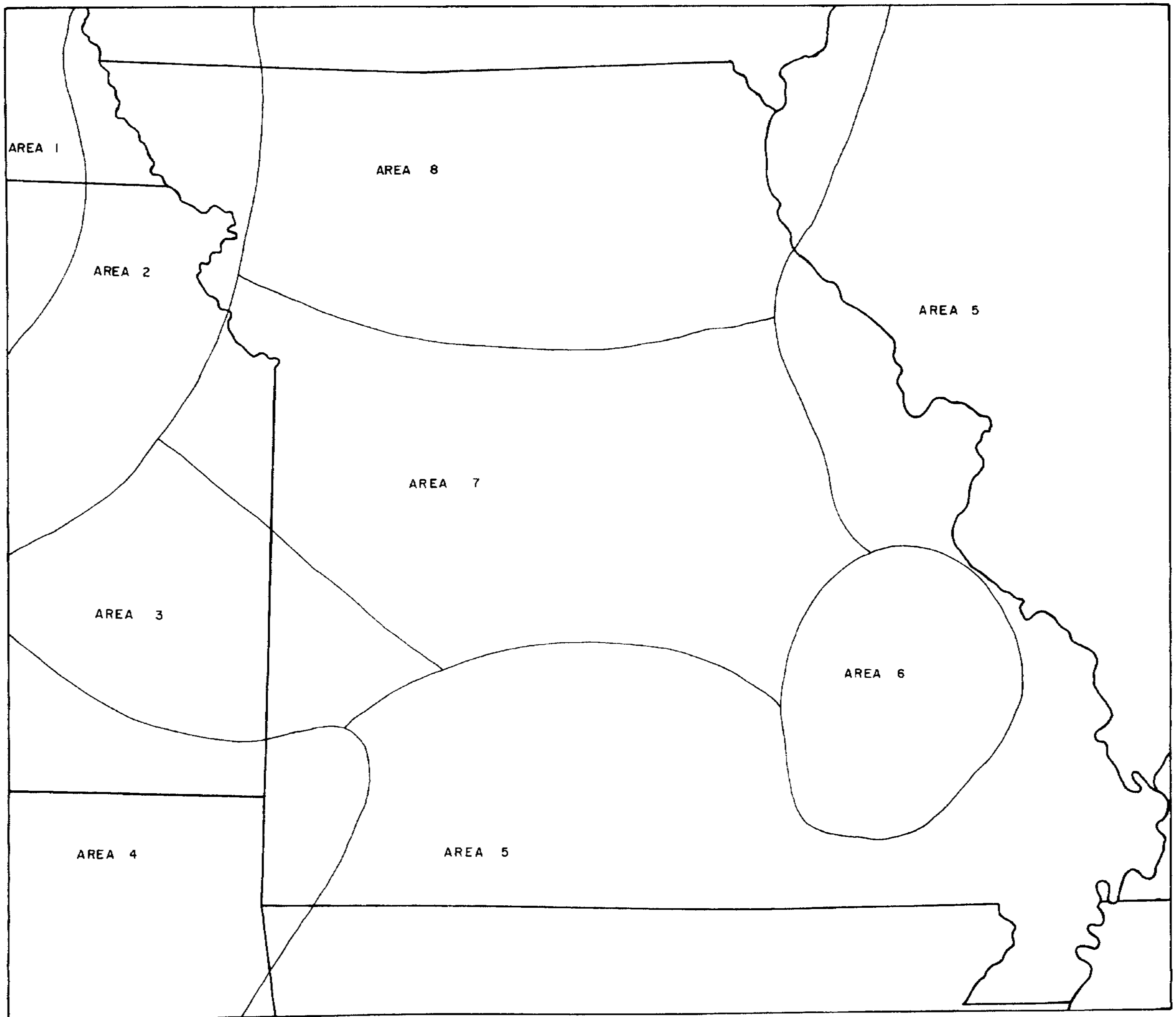


Figure 6.

the Nemaha Ridge, and Area 6, the St. Francois Mountains have the largest concentration of data points and the extreme weight which they apply to the trend surface must be considered when interpreting the resulting maps.

TABLE III

RELATIVE DATA DENSITY IN SUBAREAS

Subarea	Number of Data Points	Number of Townships in Subarea	Data Points per Township
1	47	52	.904
2	42	260	.160
3	34	234	.145
4	40	208	.192
5	34	910	.037
6	95	156	.609
7	36	520	.069
8	5	416	.012

B. Discussion of Trend Maps
for the Precambrian Surface

The trend surface program employed in this study allowed a surface up to the seventh order to be fitted to the data. All seven surfaces were calculated from Precambrian topographical data available from well logs. The results of this analysis, the coefficient of determination, a measure of the goodness of fit, the correlation coefficient and the F ratio are presented in Table IV.

TABLE IV

STATISTICAL COMPARISON OF VARIOUS TREND SURFACES

Surface order	Coefficient of Determination	Correlation Coefficient	F-Ratio
1	.2517	.5017	42.1588
2	.3468	.5889	33.0095
3	.5022	.7087	37.3293
4	NOT APPLICABLE		
5	.5553	.7452	21.3879
6	.6213	.7883	29.0886
7	.2718	.5214	3.5577
Mean = 645	Standard deviation = 627		

There was generally a better fit of data with the higher order surfaces. However, the amount of additional time required to compute the higher order surfaces may not justify the small improvement in the sum of squares and/or the additional number of major structures which were delineated in the mapping procedure. In addition, neither the fourth nor the seventh order surfaces showed this improvement. The first, second, third, fifth, and sixth order surfaces all indicate an improvement in the fit of the surface and are statistically valid at the 99.99th percentile as is evident from the F-Ratio. The seventh order surface shows a drop in the statistical parameters and is valid only at the 90th percentile.

For some reason, not yet determined, the fourth order surface analysis resulted in a "nonsense" equation and map. Several substitutions of data were tried to solve this inconsistency with no success. There are two possible explanations for this occurrence. Either the determinant for these two surfaces is too small, which would produce an ill-conditioned matrix, or the polynominal model assumed in trend surface analysis, while being a close approximation, is not a true representation of the surface. The second explanation seems to be more probable when evaluating structural data.

In trend surface analysis, the surface under consideration is separated into two components - the trend or broad regional features and the residuals, deviation from the trend or the small scale local features. To make a proper interpretation, it is necessary that both components be reviewed. The following is a brief description of the six available trend maps. The location of the main structural features described are presented in Figure 6 and Table 2.

1. First order surface.--This surface shows a north-northeast lineation parallel to the Nemaha Ridge dipping westnorthwest from the St. Francois Mountains (Fig. 7).

2. Second order surface.--Two main lineations are apparent on this surface (Fig. 8), a north-northeast lineation paralleling the Nemaha Ridge and an east-northeast lineation paralleling the southwesterly extension of the St. Francois Mountains. The St. Francois Mountains are expressed by a high. The Forest City Basin is expressed by a gentle downwarping of the surface with an upwarping again in the area of the Nemaha Ridge. There is a slight expression of the Illinois Básin as

Figure 7. First order trend map of Precambrian surface for study area.

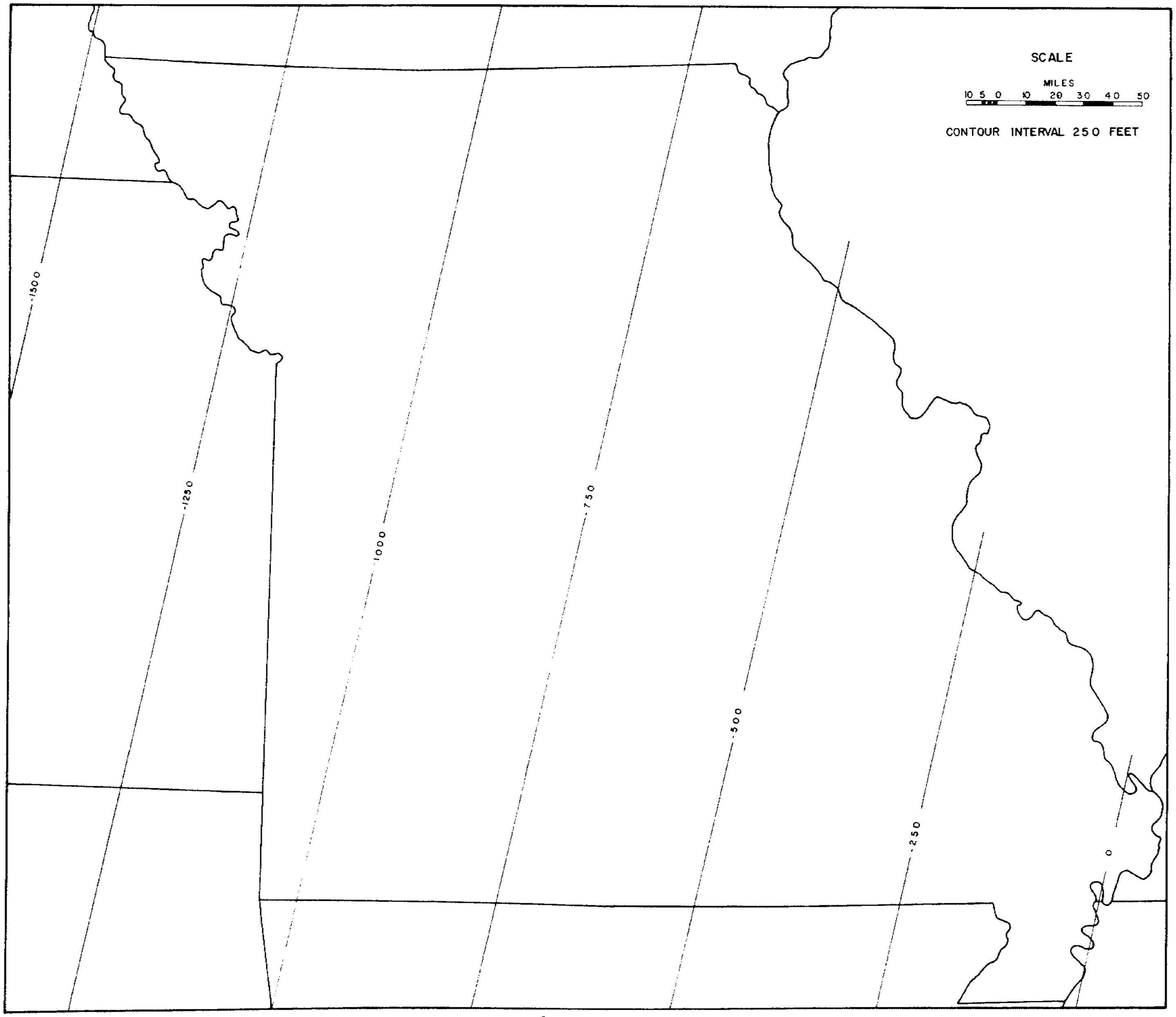

SCALE
MILES
10 5 0 10 20 30 40 50
CONTOUR INTERVAL 250 FEET
-1500
-1250
-1000
-750
-500
-250
0

Figure 7.

Figure 8. Second order trend map of Precambrian surface for study area.

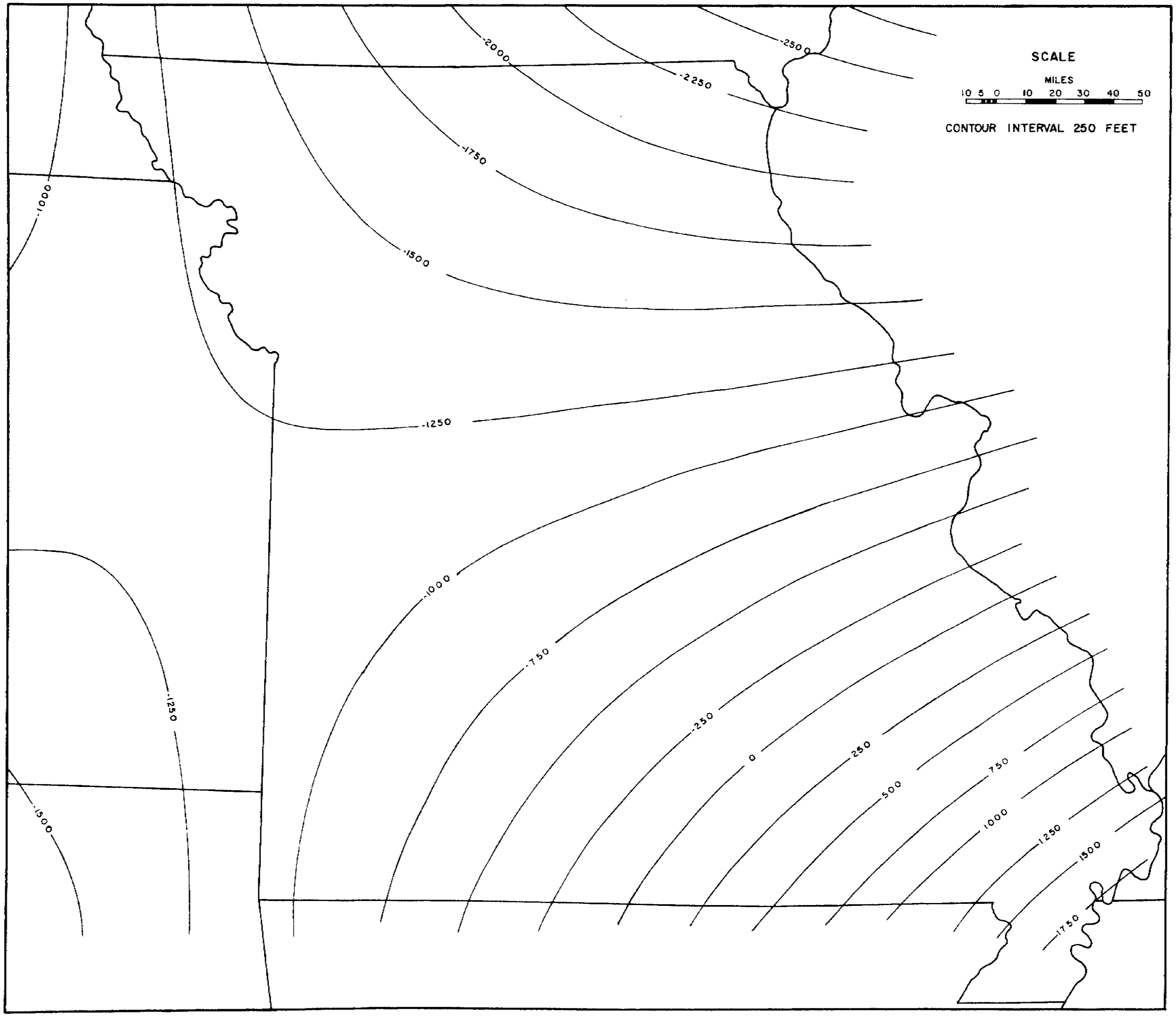

SCALE
MILES
10 5 0 10 20 30 40 50
CONTOUR INTERVAL 250 FEET
-2500
-2250
-2000
-1750
-1500
-1250
-1000
-750
-250
0
250
500
750
1000
1250
1500
1750
-1000
-1250
-1500

Figure 8.

the northeasterly part of the map continues as a low. The Cherokee Basin is also expressed by a downwarping in the southwestern part of the map.

3. Third order surface.--The Nemaha Ridge and the downwarping of the Forest City Basin appear much the same on this map surface (Fig. 9) as they did on the second order surface (Fig. 8). The main improvement noted is the closure on the St. Francois Mountains. This high shows a definite northeast strike expressing the general line of Precambrian volcanoes from Ohio to Oklahoma, the "Ancestral Ozarks" (Snyder, 1968b) which formed a continental divide during late Precambrian and the early Paleozoic.

4. Fifth order surface.--Most of the major structural features in the Missouri area can be recognized from the surface (Fig. 10). The Arkansas Basin, the Forest City Basin and the Mississippi Embayment are defined along with the Nemaha Ridge, the St. Francois Mountains, the Chautauqua Upwarp and possibly the Lincoln Fold area. Some of these features, however, are slightly exaggerated or misaligned. For example, the Forest City Basin area extends farther eastward than is generally accepted with the inflection point between the Forest City Basin and the Illinois Basin assuming a much more northerly strike than fits the known occurrences.

5. Sixth order surface.--This surface (Fig. 11) is quite similar to the fifth order surface (Fig. 10). The main ap-

Figure 9. Third order trend map of Precambrian surface for study area.

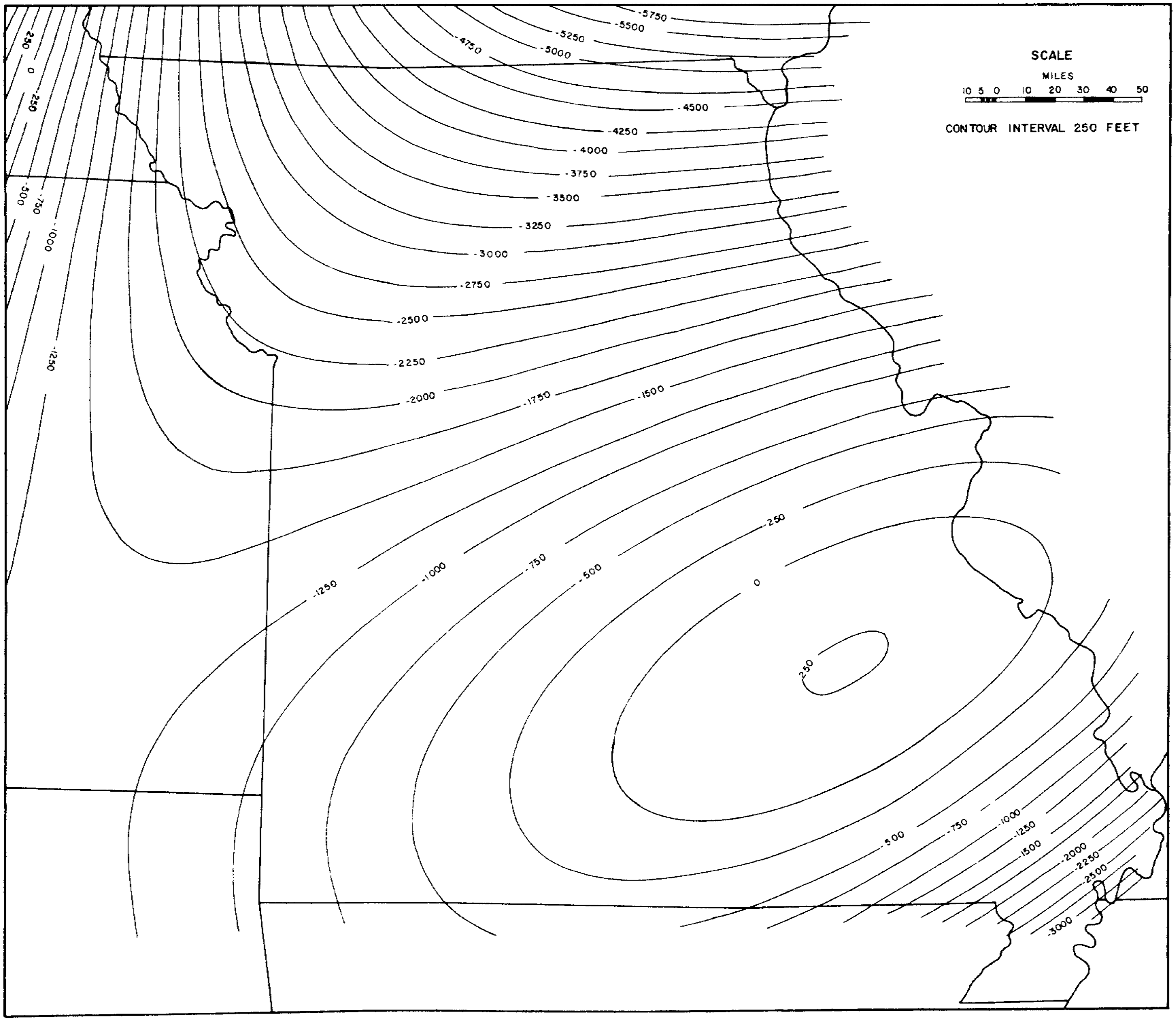

SCALE
MILES
10 5 0 10 20 30 40 50
CONTOUR INTERVAL 250 FEET
-5750
-5500
-5250
-5000
-4750
-4500
-4250
-4000
-3750
-3500
-3250
-3000
-2750
-2500
-2250
-2000
-1750
-1500
-1250
-1000
-750
-500
-250
0
250

Figure 9.

Figure 10. Fifth order trend map of Precambrian surface for study area.

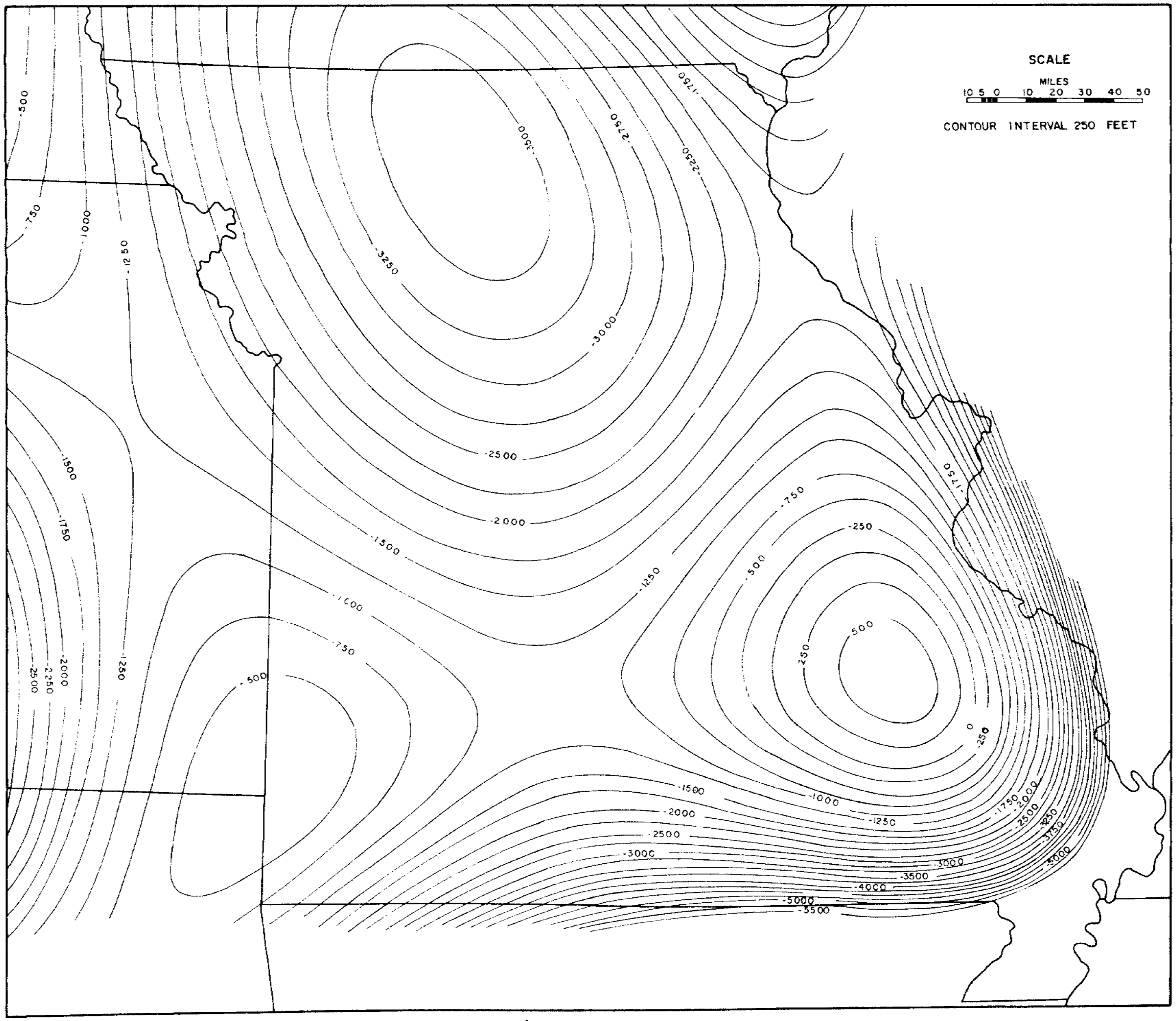

SCALE
MILES
10 5 0 10 20 30 40 50
CONTOUR INTERVAL 250 FEET
-500
-750
-1000
-1250
-1500
-1750
-2000
-2250
-2500
-1750
-2250
-2750
-3000
-3250
-3000
-2500
-2000
-1500
-1250
-1000
-750
-500
-750
-250
-500
-250
250
500
0
-250
-1500
-1000
-1250
-2000
-2500
-3000
-3000
-3500
-4000
-5000
-5500
-1750
-2000
-2500
-3250
-3750
-5000

Figure 10.

Figure 11. Sixth order trend map of Precambrian surface for study area.

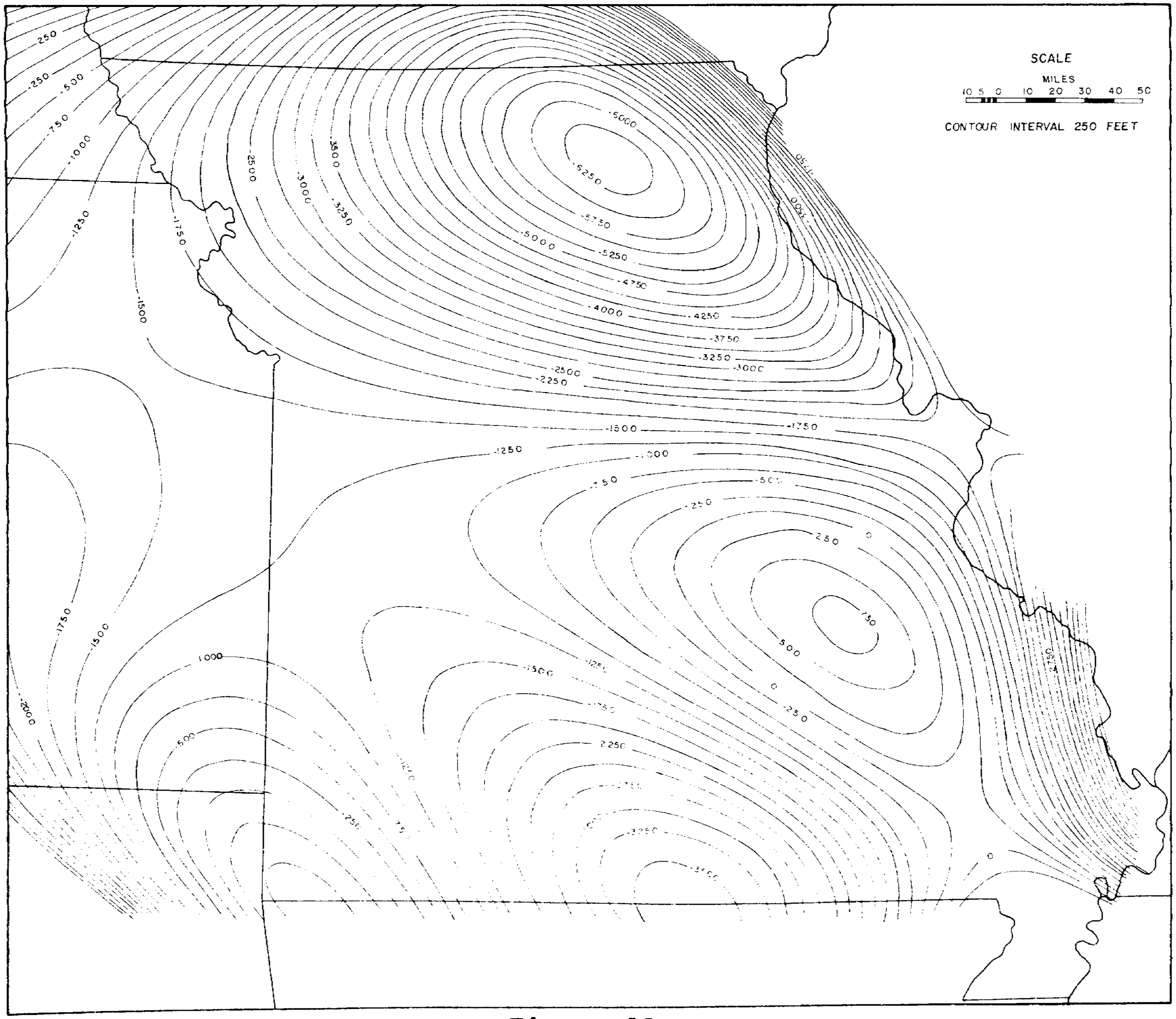


Figure 11.

parent difference is the strong northeast lineation of all the southern structures. In addition, the Nemaha Ridge is a much less prominent feature on this surface than any of the previous surfaces.

6. Seventh order surface.--The relationship between the Nemaha Ridge, the Forest City Basin, the Illinois Basin, the Lincoln Fold area, the St. Francois Mountains and the Chautauqua Uplift area is a fairly clear representation of existing structure (Fig. 12). The southerly part of this map does, however, have a completely unrealistic appearance.

C. Comments on Observation from Trend Maps

It is obvious that known structural conditions may be defined and represented by trend analysis. Without a fairly good understanding of the basic structural features in an area, interpretation of trend maps of high order is a risky procedure since as these higher order surfaces are employed, more "forcing" must be done to fit the data and some very unrealistic maps can be obtained. Also, the problem of unequal weighing of data points must be considered before interpretations can be made.

The high density of data points in the area of the Nemaha Ridge and the area of the St. Francois Mountains weighed the trend surface to the degree that on the lower order surfaces these two features dominate. The higher order surfaces show more inflection and the effect of each area and its appearance

Figure 12. Seventh order trend map of Precambrian surface for study area.

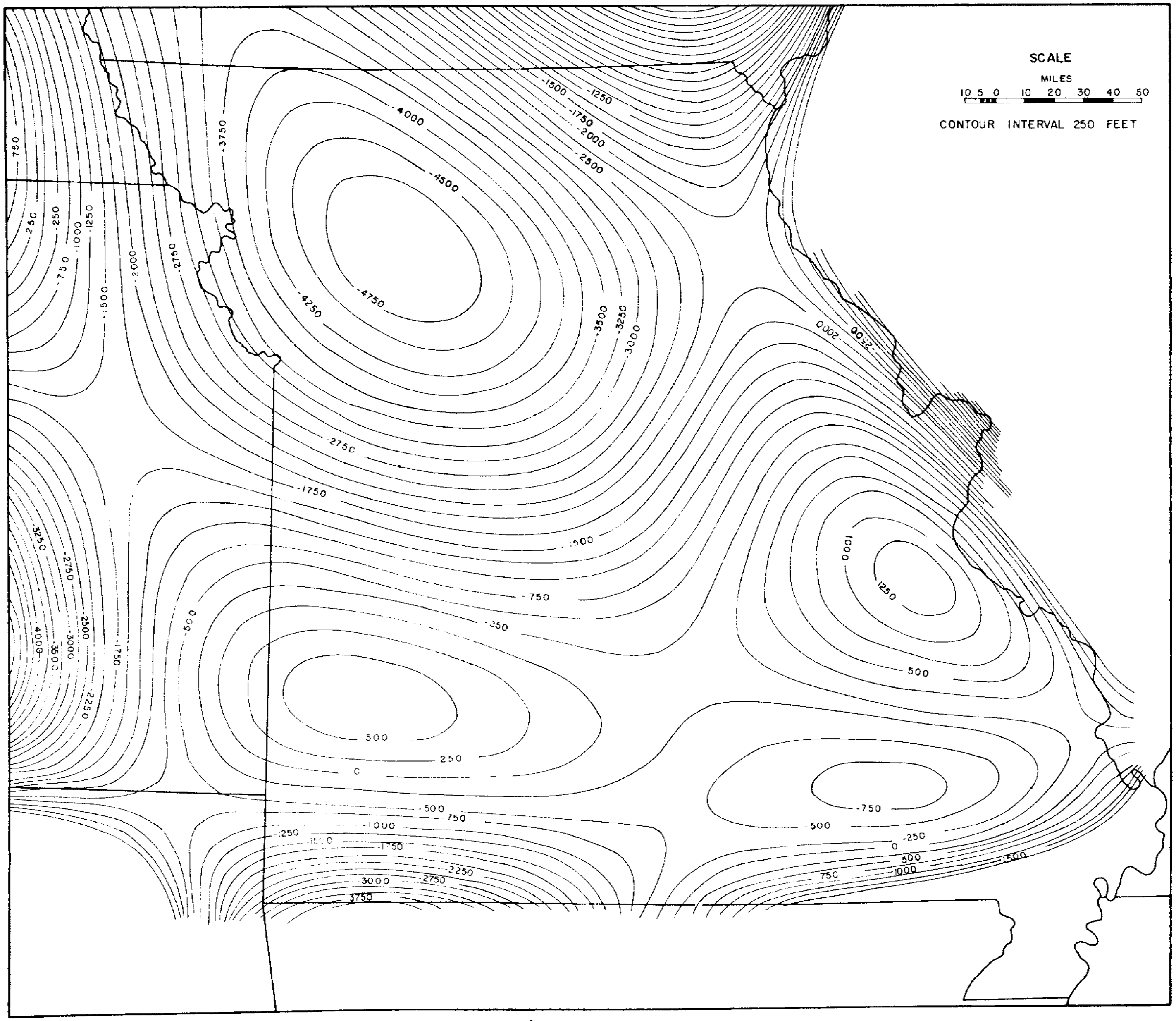

SCALE
MILES
10 5 0 10 20 30 40 50
CONTOUR INTERVAL 250 FEET
-4000
-4500
-4750
-4250
-3750
-1500
-1250
-1750
-2000
-2500
-3500
-3250
-3000
-2750
-1750
-1500
-750
-250
500
250
1250
1000
500
-750
-500

Figure 12.

on these maps is indirectly related to the data density.

All major structure in the Missouri area can be delineated from observation of the trend maps.

A strong northwest structural trend is apparent in north and central Missouri.

The southwesterly trending band of volcanics which outcrop as the St. Francois Mountains is a controlling structural feature.

V. DISCUSSION OF RESIDUAL MAPS OF PRECAMBRIAN SURFACE

The residuals from the third and sixth order trend surfaces were plotted and contoured and are presented in Figures 13 and 14 respectively. The sixth order surface was chosen because it gave the best statistical representation of the Precambrian surface as designated by the coefficient of determination, correlation coefficient, and F-Ratio. The third order surface was chosen because it is the lowest order surface which expresses the general configuration of the Precambrian surface.

On the Precambrian residual maps, 600 feet was selected as indicative of a strong residual high as 600 feet is a convenient approximation of the value of one standard deviation, 627 feet.

A. Area 1

The main structural feature in this area is the Nemaha Ridge. This very abrupt north-trending feature has the same configuration on both the third and sixth order residual maps.

The eastern margin of this area is marked by a very abrupt change in contour values which is a result of strong faulting. The eastern margin becomes less rugged and abrupt to the south reflecting the fact that faulting becomes less

Figure 13. Third order Precambrian residual map of study area.


SCALE
MILES
10 5 0 10 20 30 40 50
CONTOUR INTERVAL 200 FEET
MINING DISTRICT
+600 RESIDUAL AREA
CENTRAL MISSOURI
INDIAN CREEK
OLD LEAD BELT
VIBURNUM TREND
MINE LA MOTTE
ANNAPOLIS
TRI-STATE

Figure 13.

Figure 14. Sixth order Precambrian residual map of study area.

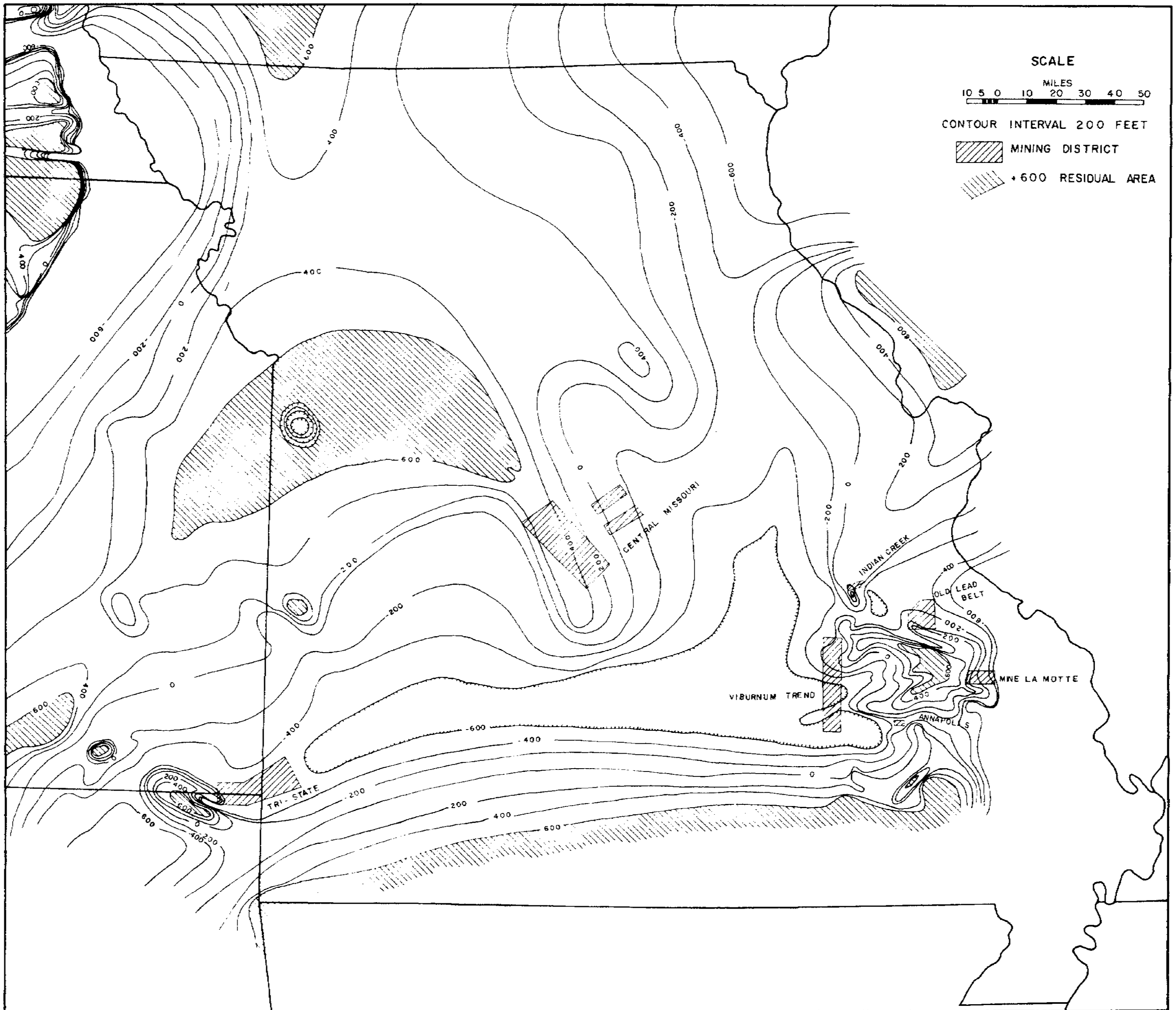

SCALE
MILES
10 5 0 10 20 30 40 50
CONTOUR INTERVAL 200 FEET
MINING DISTRICT
+600 RESIDUAL AREA
CENTRAL MISSOURI
INDIAN CREEK
OLD LEAD BELT
VIBURNUM TREND
MINE LA MOTTE
ANNAPOLIS
TRI-STATE

Figure 14.

intense southward. Examination of the contour maps also shows the presence of many strong east-west deflections reflecting numerous cross faults in the area. While strong faulting and uplift are the main factors producing the expression seen on the two maps, it is probable that the Nemaha Ridge was a positive feature during the early Paleozoic and that part of the reflection seen is the result of original topography.

B. Area 2

The main structural feature in this area is the Forest City Basin. The shape of this feature as seen from the residual maps coincides extremely well with the generally accepted shape of the Forest City Basin as outlined by Anderson and Wells (1968). It is of interest to note the general parallelism of this feature with the belt of Keeweenawan Clastics as outlined by Snyder (1968a, 1968b) (Fig. 2). It is also of interest to note that the Iowa well, Wilson #1 (see Appendix 4) lies at the edge of this feature. This well contains a very thin Lamotte equivalent section and a very thick Precambrian clastic sequence. It appears from the Lamotte data and the residual information that the Forest City Basin area was a strongly negative structure during the Keeweenawan when the Precambrian clastics were deposited. Subsequently, this material was a major source for the Lamotte Sandstone. This area was, therefore, a basinal area during the Precambrian, but during the early Paleozoic it was a neutral to slightly positive area, becoming negative again during the Ordovician.

C. Area 3

The major structural features in this area are a series of northwest-trending faults (McCracken, 1971 and Cole, 1962). On the residual maps the main features are three residual highs which fall directly on these northwest-trending fault systems. Although all three of these features appear definite on the third order map, the middle feature is only an inflection on the sixth order map and the western high has become subdued. The easterly high is in the area of the pre-upper Cambrian deposits described by Skillman (1948) and this area was probably a slight high during the early Paleozoic.

D. Area 4

The main structural features in this area are a series of northwest and northeast-trending fold systems, the main ones being the Miami Trough, the Seneca Trough, the Bendelare Trough, and the Picher Anticline. While these are fold features, there is a large amount of small scale faulting associated with these features. There are also many known Precambrian highs in this area.

Of interest on the maps is the criss-crossing relationship of the residuals. The highs show a general northwest trend through the Tri-state area extending as an expression of the Chautauqua High. The lows, especially on the sixth order map, exhibit a very strong northeast trend.

The data density in this area is approximately average and therefore this area's influence on the trend surface is average. It should be noted that the residual highs maintain their approximate relationship on both the third and sixth order residual maps.

While the Tri-state district as defined extends approximately 100 miles east-west and 30 miles north-south, the majority of the production has come from the western part of the district. The Picher Field, the most westerly subdistrict has accounted for 61 per cent of the total district's production (Brockie, Hare and Dinges, 1968). On both residual maps it can be seen that the Picher Field is abutting a strong residual high. The necessary structural condition for emplacement of a Mississippi Valley-type deposit has therefore been fulfilled.

E. Area 5

The main structural features in this area are three major negative features - the Arkansas Basin, the Mississippi Embayment and the Illinois Basin. There is very little data available in this area but the third order residual map does indicate that these areas are, and probably were, negative areas during the early Paleozoic as most of the area is shown as a strong residual low. The sixth order map does a semi-adequate job of portraying the Illinois Basin and the Mississippi Embayment; however, the Arkansas Basin area is shown as a strong residual high. What probably is being indicated is that during early Paleozoic southern Missouri, while not being a high, was a slightly positive to neutral shelf area. This might also be interpreted as an indication of the northeast-trending belt of volcanics (Snyder, 1968a, 1968b) which were a continental divide during late Precambrian-early Paleozoic time. The strong residual basin extending westward from the St. Francois Mountains probably was a more negative area than its surrounding features.

F. Area 6

The main structural feature in this area is the St. Francois Mountains. The inflection seen on the residual maps is a result of the original relief on the Precambrian surface, the strong upwarping, not all of which has been removed by the trend surface, and the faulting throughout the area. The faulting is best illustrated on the residual maps by the closely spaced contour lines in the periphery regions east of Indian Creek and south of the Mine LaMotte area.

The data density in Area 6 is quite high. This weights the trend surface and forces it to conform quite closely to the structural data with the result that the residuals are much closer to zero than would be the case with a uniform data density throughout the study area. This being the case, with uniform data density the area of strong residual highs would be larger. At Mine LaMotte, Indian Creek and Annapolis the ore bodies are strongly controlled by the location of Precambrian knobs. This is also true but not as obvious for the Old Lead Belt. An examination of the residual maps shows that if the residual highs were extended outward the peripheral relationships that these districts now show would become an abutting relationship as was the case for the Picher Field in Area 4.

The deposits of the Viburnum Trend do not appear to have a strong relationship with Precambrian highs. This is apparent on the residual maps as even with extension of the residual highs this subdistrict would not show an abutting relationship with areas of strong residual highs. Therefore, the configuration of the Precambrian topographic surface must not be one of the major controlling factors for emplacement of these deposits.

G. Area 7

This area, the general mid-Missouri area, has no extremely strong structural features but has many northwest-trending structural lineaments superimposed on a general neutral structural background. The Proctor Anticline and the Decaturville crypto-volcanic structure are combined and expressed by the strong residual high in south-central Missouri, The Belton Fault complex is expressed by the closed residual lows in west-central Missouri. The northwest structural lineations are expressed on the third order residual map but the general northwest trend is best shown on the sixth order residual map.

The data density throughout this area is generally low so that the residuals are probably more pronounced than would be the case with uniform data density. The central Missouri district presents an interesting paradox as it is abutting a residual high on the third order residual map whereas on the sixth order residual map this district is far removed from a strong residual high. This district comprises about 2,000 square miles which include many ore deposits too small or too low grade to be profitably mined for lead or zinc. As the sixth order surface tends to be a better representation of the true surface conditions and also by definition removes more of the regional components from the residual map than the third order surface, it would appear that the conditions necessary for the emplacement of a major Mississippi Valley-type deposit were not present in a great enough degree for this area to be a major mineral district.

H. Area 8

This area is a generally neutral area dividing two large basins, the Forest City and the Illinois, best illustrated by the north-trending residual high on the sixth order residual map. This area has most probably been an inflection area since the early Paleozoic and served as a low divide during deposition of the Lamotte Sandstone.

VI. TREND ANALYSIS OF THE LAMOTTE FORMATION

The unequal areal distribution of available samples of Lamotte Sandstone did not permit a complete trend surface analysis to be carried out on a state-wide basis. The majority of samples were from the western side of the St. Francois Mountains with the greatest concentration in the area of the New Lead Belt.

In addition, as noted, the basal Bonneterre is, in many areas, a sandstone. This has lead to confusion in the past in that different workers have used different criteria in the selection of the Lamotte-Bonneterre contact. It was felt, therefore, that it would be impossible to obtain a constant stratigraphic horizon from examination of well logs.

A potential application of trend surface analysis, however, is to compare results prepared by different investigators or from different defining criteria by evaluating the degree of fit between two resulting surfaces using the same X and Y map coordinates, allowing only the two Z coordinates to vary. In this case Z_1 would be the top of the Lamotte as shown on well logs and Z_2 the top of the Lamotte based on the criteria listed in Table II. The probable explanation for a poorly fitting surface would be that a constant stratigraphic horizon was not used to define the top of the Lamotte.

To test this hypothesis, eighty borings were selected which had previously been logged and for which samples were still available for evaluation. These wells were from the area of the Viburnum Trend. The results of the trend surface analysis of this study are presented in Table V.

The trend surfaces for the top of the Lamotte as chosen using the criteria listed in this study were slightly subdued replicas of the Precambrian trend surfaces. In addition, with the exception of the fifth order surface, the top of the Lamotte as picked using these criteria gives a much better mathematical fit than the top of the Lamotte as picked from well logs. This suggests that the most probable reason a better fit was obtained is that the top of the Lamotte as chosen in this study is a better representation of a uniform stratigraphic horizon.

By the same token, it would appear that in any study of this type, if the surface is ill fitting, it may be an indication that some mistake has been made in the geological interpretation.

TABLE V

COMPARISON OF LAMOTTE CONTACT

	FROM WELL LOGS			FROM STUDY		
Order Surface	Coefficient of Determination	Correlation Coefficient	F Ratio	Coefficient of Determination	Correlation Coefficient	F Ratio
1	.2198	.4689	7.2319	.3749	.6123	17.3934
2	.4705	.6859	10.9579	.6778	.8233	29.4496
3	.7188	.8478	17.8894	.8245	.9080	37.5747
4	.3184	.5643	2.0245	.8361	.9144	25.5118
5	.7484	.8651	8.3581	.5429	.7368	3.9032
6	.8177	.9043	8.3301	.8663	.9307	14.3461
7	.2068	.4548	.3187	.8878	.9422	11.8703
	Mean = -262			Mean = -277		
	Standard deviation = 391			Standard deviation = 181		

VII. RESIDUAL ANALYSIS OF THE LAMOTTE FORMATION IN THE AREA OF THE VIBURNUM TREND

In the previous discussion it has been shown that there is a strong relationship between Precambrian residual highs and the occurrence of Mississippi Valley-type deposits (Figs. 13 and 14). In the area of the Viburnum Trend this relationship appears to break down as this mineral district cuts across the trend of the Precambrian residual contours. Figure 15 is an enlargement of Figure 13 showing the contours, outline of the Viburnum Trend and mine locations in this area.

Since the bulk of the ore in the Viburnum Trend to date has been found stratigraphically higher in the Bonneterre than in the other subdistricts of southeastern Missouri, it follows that the configuration of the Lamotte surface may be a more reliable guide. If the residuals from trend analysis of the Lamotte are compared with the outline of the Viburnum Trend (Fig. 16) a much better relationship is observed than for the Precambrian residuals (Fig. 15).

The improvement in the relationship between the residuals from the trend surface and the position of the Viburnum Trend is probably a result of the filling of valleys and basins by early Lamotte deposition which altered the original Precambrian surface topography, and the environments of deposi-

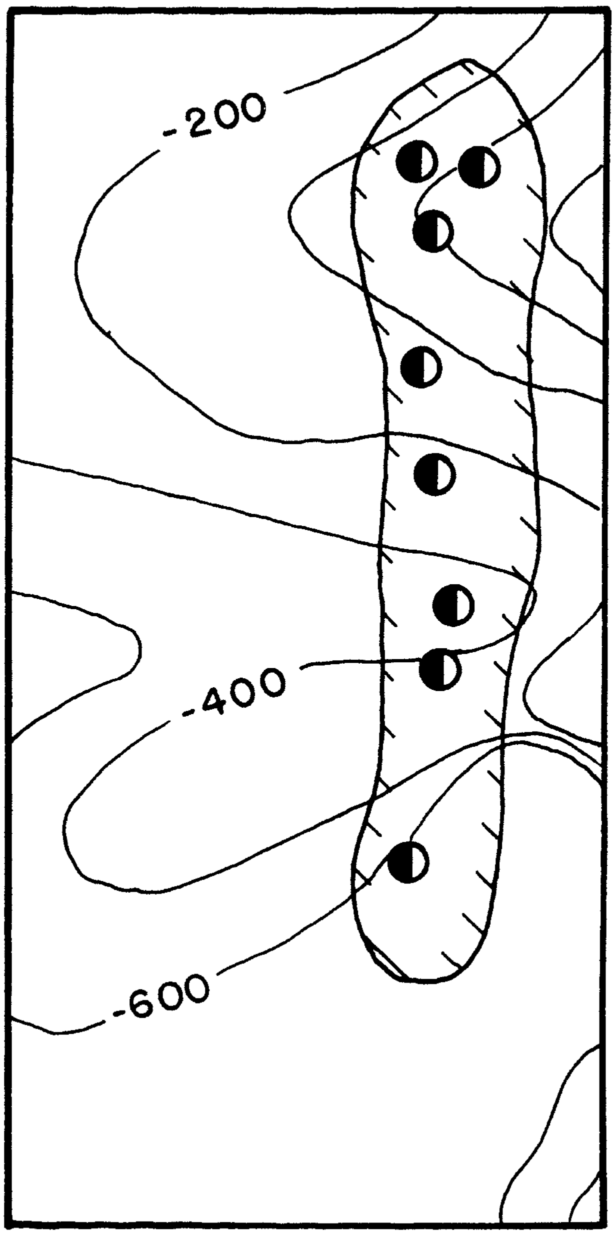


Figure 15. Enlargement of third order residual map for Precambrian surface in area of Viburnum Trend with outline of trend and major mine locations. Approximate scale = 1:500,000.

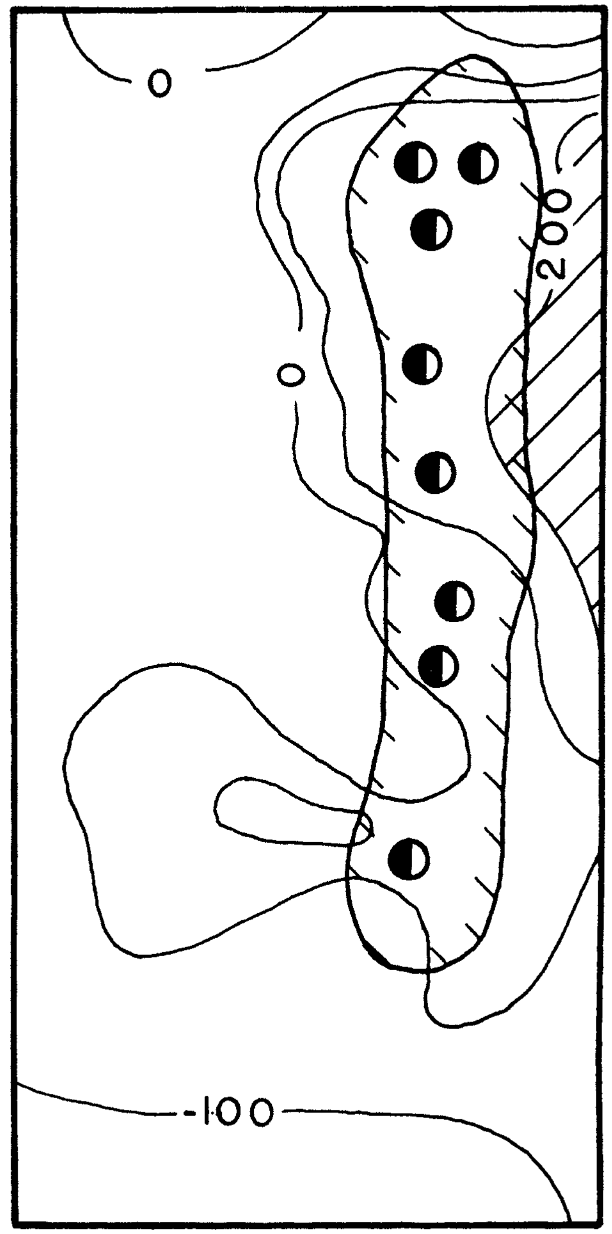


Figure 16. Third order residual map for Lamotte Sandstone in area of Viburnum Trend with outline of trend and major mine locations. Approximate scale = 1:500,000.

tion thus were changed. In the case of the Viburnum Trend, the valley between the two Precambrian highs was filled and subsequent Lamotte and Bonneterre were deposited on a surface roughly conforming to the most westerly extent of the preexisting Precambrian highs.

The relationship between the mineral deposits and the preexisting Lamotte topography is strongly evident in the northern reaches of the Viburnum Trend. For the Precambrian residual map, 600 feet was selected as indicative of a strong residual high as it was a convenient approximation of one standard deviation. One standard deviation of the Lamotte surface is 181 feet. Therefore, if the 200 foot contour is selected as indicative of a strong residual high on the Lamotte residual map this abutting relationship of mineral deposits to residual highs becomes more apparent.

At the trend's southern extremes, however, it appears that the basal Bonneterre also strongly changed the depositional topography and the relationship is not well defined.

Trend surface analysis using a horizon in the lower Bonneterre probably would show the relationship better in this area.

VIII. CONCLUSIONS

The similarity in the controlling factors necessary for the emplacement of Mississippi Valley-type ore deposits allows these conditions to be expressed mathematically as a function of pre-formational topography and post-formational structure. Through the use of trend surface analysis, areas which satisfy these conditions can be recognized through examination of residual maps of a structural surface below the ore horizon. The similarity of appearance of the Tri-state, central Missouri, and southeastern Missouri districts on the residual maps verifies this hypothesis and also indicates a very strong genetic relationship between these districts. The detailed examination of the Lamotte Formation in the area of the Viburnum Trend illustrates an even better relationship between residual highs and the ore deposits of the Viburnum subdistrict.

The large scale structural features in the area of study are expressed on trend maps of the Precambrian surface. Areas of high data density overly influence the shape of the trend surface but more of the general configuration is expressed with the higher order surface. Caution must be used when interpreting higher order surfaces, however, as areas of poor control may be expressed by a completely unrealistic appearance.

An examination of the literature for other areas of Mississippi Valley-type deposits strongly suggests that the methods employed in this study could provide an excellent exploration tool. Other areas which contain deposits not normally considered Mississippi Valley-type may also prove to be locatable with this method.

The work of Wertz (1971) appears to point this out since the conditions necessary for the formation of deposits in the southeastern Arizona copper district can be expressed with mathematical expressions similar to those used to express Mississippi Valley-type deposits.

It is speculation to predict the applicabilities of trend surface analysis in the exploration for other sedimentary mineral deposits. The contribution of post-formational structure may be pre-or post-mineralization and areas which appear to have the proper conditions may prove to yield only barren structures. If this is recognized, however, it can be seen that ore deposits are simply the concentration of an economic material to a degree large enough that profitable recovery becomes feasible. For this to occur, structural and stratigraphic conditions in the area of the deposit must be significantly different (anomalous) from the surrounding area to provide a favorable environment for accumulation. As trend surface analysis, by definition, is a method whereby anomalous features can be identified, isolated, and studied, there is every reason to anticipate that with modification, trend surface analysis may be used as an aid in the location of almost any mineral deposit in sedimentary materials.

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VITA

John Siegfried Trapp was born on January 1, 1942 in Enderlin, North Dakota. He is the son of Mr. and Mrs. Otto Trapp of Enderlin. He received his primary and secondary education in the Enderlin Public School system. In June 1967 he received a Ph.B. degree in geology from the University of North Dakota in Grand Forks, North Dakota.

Mr. Trapp served three years in the United States Army and has received an honorable discharge.

Mr. Trapp was enrolled in the graduate school of the University of Missouri at Rolla from September 1967 to June 1971 and was a graduate teaching assistant in the Department of Geology. In May 1969 he received a Master of Science degree in geology from the University of Missouri at Rolla.

In June 1971 Mr. Trapp accepted employment with Cerro Mineral Corporation as an exploration geologist. In January 1972 he returned to University of Missouri at Rolla to complete his requirements for a Ph.D. in geology.

Mr. Trapp is married to the former Julie Anne Fiala and they have two children, Laura Anne and John Siegfried II.

Appendix 1

DEEP WELL DATA

County	Well number	Location[1]	Depth to top of Lamotte[2]	Depth to top of Precambrian[3]	Ground elevation
		MISSOURI			
Adair	11294	61N-15W-08	2800	2985	984
Atchison	17861	64N-40W-33	--	3708	898
Barton	1620	32N-30W-29	--	1858	970
	2234	30N-33W-01	--	1685	889
Bates	2088	38N-31W-23	1425	1585	787
	2382	38N-31W-14	--	1612	800
	20465	38N-33W-11	1765	--	866
	21594	38N-33W-11	--	1900	879

[1]Location is given in the order of township, range, section.

[2]A dash in this column signifies that the sample from this well was not studied. The footage in this column is the depth to the top of the Lamotte as placed by the author. NL signifies that no Lamotte was encountered in this well.

[3]A dash in this column signifies that the well did not penetrate the Precambrian.

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Boone	18139	50N-12W-20	1885	2005	882
Camden	13945	37N-16W-32	NL	550	1055
Carter	21589	27N-01W-12	1630	1736	649
	21668	27N-01W-15	NL	1335	706
	22002	27N-01W-12	1650	--	660
	0-21	27N-02E-03	NL	1800	720
Cass	9118	46N-33W-29	--	2395	993
	15420	44N-33W-04	--	2185	972
Clark	18404	54N-06W-05	--	2930	565
Crawford	8526	39N-03W-03	1310	1475	903
	19720	36N-04W-23	1160	--	1140
	12285	35N-02W-16	NL	690	1080
	12302	35N-02W-16	NL	745	1056
	12309	35N-02W-09	NL	570	964
	12313	35N-02W-09	--	715	1000

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Crawford	12310	35N-02W-09	--	935	1097
	0-19	35N-02W-14	--	855	792
	0-29	35N-03W-27	924	--	1020
Dent	1666	34N-05W-07	1365	--	1154
	2246	34N-06W-03	1445	1750	1181
	0-75	34N-02W-16	1135	1443	1229
	0-22	35N-04W-25	--	1295	1340
	0-30	34N-03W-02	1115	--	1200
	0-31	34N-03W-10	979	--	1160
	0-32	34N-03W-12	1146	--	1210
	0-33	34N-03W-25	1271	--	1280
	0-34	34N-02W-31	1191	--	1290
	0-46	34N-02W-06	1121	--	1205
	0-63	34N-02W-17	1077	1390	1183
	0-69	34N-02W-04	1126	--	1126

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Dent	0-74	34N-02W-20	993	--	1070
Douglas	25825	26N-17W-24	1620	--	1041
Franklin	2467	42N-01W-36	--	1355	697
	17328	41N-02W-18	--	1605	735
	26270	44N-02W-13	--	2235	580
Gasconade	26234	44N-06W-34	1430	1750	555
	26243	44N-06W-19	1505	1710	555
	26246	44N-04W-06	--	2160	660
	26254	45N-04W-06	1865	2245	640
	26261	45N-06W-31	--	1825	520
Hickory	4580	37N-21W-02	--	1530	1226
Howell	3011	26N-08W-28	--	2500	1150
Iron	2411	30N-04E-08	NL	505	535
	3144	35N-01E-36	--	765	1180
	3596	31N-03E-24	NL	420	598

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Iron	4853	33N-04E-21	NL	50	1130
	5353	33N-04E-05	NL	425	1007
	6717	34N-04E-32	NL	115	915
	6725	34N-04E-32	NL	115	930
	9577	31N-03E-14	--	540	835
	9661	31N-03E-14	NL	255	785
	9666	31N-03E-13	NL	540	645
	9859	31N-03E-14	NL	610	739
	9944	31N-03E-13	NL	280	824
	10217	33N-04E-05	--	300	921
	11454	34N-04E-32	NL	220	909
	11707	31N-03E-14	NL	460	669
	11852	31N-03E-23	NL	682	681
	11957	34N-04E-30	NL	60	1026
	12293	35N-01W-20	NL	580	1173

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Iron	12433	33N-04E-05	NL	225	904
	13208	35N-01W-20	--	765	1124
	13850	34N-04E-30	NL	195	925
	14458	33N-04E-04	NL	165	935
	18839	34N-02W-03	1105	--	1255
	19514	34N-01W-06	NL	800	
	19697	34N-01W-03	--	590	1095
	20207	35N-01E-30	NL	525	1292
	20254	35N-01W-23	780	--	1260
	20272	35N-01W-26	770	--	1239
	20363	35N-01E-30	675	--	1183
	20380	35N-01E-21	NL	580	
	0-14	33N-03E-03	NL	75	1084
	0-15	33N-04E-03	NL	70	904
	0-56	31N-02W-06	1507	--	1290

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Iron	0-70	34N-02W-15	1135	--	1368
	0-71	34N-02W-21	1076	--	1140
Jackson	2096	47N-31W-27	--	2214	966
	3061	50N-30W-17	2155	2275	772
	19211	50N-29W-17	--	2265	705
	0-68	50N-29W-17	2150	2270	708
Jasper	1533	28N-31W-03	--	1950	955
	1872	28N-31W-03	--	1820	955
	6507	28N-32W-36	1575	1730	970
Jefferson	12590	39N-04E-19	675	--	804
LaClede	24490	34N-15W-34	1446	1645	1070
	24544	33N-14W-20	1593	1825	1183
	24670	33N-15W-14	1590	1825	1183
	0-23	33N-15W-23	--	1835	1178
LaFayette	20186	49N-29W-01	2020	2175	776

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Madison	2152	31N-05E-27	NL	460	590
	2159	31N-05E-13	NL	485	500
	2384	33N-07E-22	--	400	910
	8356	33N-07E-13	NL	395	833
	8391	33N-07E-13	NL	420	815
	8393	33N-07E-24	NL	340	791
	8396	33N-07E-13	NL	390	822
	8409	33N-07E-34	--	700	925
	8492	34N-07E-26	--	655	915
	9016	32N-06E-19	NL	235	620
	9042	33N-07E-30	NL	305	748
	9047	32N-05E-25	NL	515	660
	9079	32N-06E-18	NL	160	740
	9083	32N-05E-26	NL	325	580
	9116	33N-07E-30	NL	285	770

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Madison	9117	33N-07E-30	--	320	750
	9288	33N-07E-30	NL	350	755
	9296	33N-07E-30	NL	261	745
	9329	33N-07E-06	--	122	784
	9603	33N-07E-35	--	747	947
	9703	33N-06E-02	NL	62	895
	9761	33N-06E-12	--	200	795
	9849	33N-06E-12	NL	75	782
	9850	33N-06E-12	NL	60	758
	9853	33N-06E-12	NL	45	775
	9854	33N-06E-12	NL	45	776
	9857	33N-06E-12	NL	105	752
	10245	33N-07E-15	NL	205	774
	10247	33N-07E-15	NL	170	783
	10248	33N-07E-15	NL	165	791

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Madison	10249	33N-07E-15	NL	170	779
	10251	33N-07E-15	NL	160	785
	10252	33N-07E-15	NL	170	774
	10253	33N-07E-15	NL	190	794
	10254	33N-07E-15	NL	125	792
	10256	33N-07E-15	NL	85	784
	10257	33N-07E-15	NL	235	788
	10525	33N-07E-15	NL	280	830
	11533	31N-07E-05	NL	865	805
	11549	32N-07E-36	NL	735	655
	11702	31N-08E-16	NL	1605	55
	11733	33N-07E-26	--	630	955
	11735	33N-07E-26	--	590	989
	25310	32N-08E-15	NL	525	650
	0-9	33N-07E-24	NL	310	849

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Madison	0-10	33N-07E-24	NL	480	830
	0-11	33N-07E-26	--	700	942
	0-12	32N-07E-22	NL	1435	805
	0-13	32N-08E-27	NL	1320	600
McDonald	15388	21N-34W-10	NL	1450	1015
Morgan	8405	42N-19W-04	--	1465	1061
Oregon	0-61	25N-06W-07	1986	2198	745
Osage	26236	45N-07W-20	--	1879	610
	26288	44N-08W-03	--	1843	630
Pettis	12283	45N-21W-23	--	1530	790
	16376	45N-21W-15	--	1480	781
	21765	45N-21W-33	1265	1465	812
Phelps	5354	37N-09W-22	1220	--	718
Platte	11469	53N-36W-15		2745	777
Polk	2084	33N-23W-25	--	1740	1140

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Ralls	2341	55N-04W-28	1900	2190	502
	14138	55N-05W-34	NL	1685	721
Reynolds	9193	32N-02E-06	NL	185	771
	11886	32N-02E-04	NL	150	704
	19430	33N-01W-31	--	1210	965
	19703	33N-01W-04	875	--	1043
	19737	28N-01W-12	NL	1680	870
	19973	32N-02W-33	--	1877	1240
	21057	30N-02E-03	--	1425	856
	21245	30N-01E-04	1095	1450	832
	21246	31N-02E-32	--	1470	952
	21324	30N-02E-03	1076	1326	769
	21326	30N-01E-06	1310	--	1030
	21377	29N-01E-24	1225	1375	731
	21385	28N-01E-09	1515	--	870

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Reynolds	21389	29N-01E-18	NL	1230	1039
	21521	28N-01E-04	1320	1405	866
	21545	28N-01E-08	NL	1305	737
	21555	29N-01E-30	--	1205	821
	21597	29N-01E-28	NL	980	893
	21599	33N-01E-13	656	--	697
	0-24	33N-03W-20	--	1415	1050
	0-25	32N-01W-30	--	1010	957
	0-26	32N-01W-30	--	1029	920
	0-27	32N-02W-01	--	1384	1034
	0-28	32N-01W-29	--	1665	1165
	0-35	33N-02W-06	1288	--	1255
	0-36	33N-02W-07	1474	--	1340
	0-37	33N-02W-13	1419	--	1365
	0-38	32N-02W-09	1370	--	1160

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Reynolds	0-39	30N-01E-06	1310	--	1030
	0-40	32N-02W-13	1574	--	1245
	0-48	33N-03W-02	1418	--	1410
	0-49	33N-02W-21	1418	--	1035
Saline	12328	48N-23W-08	1760	1960	704
Shannon	8762	28N-03W-18	NL	40	868
	8765	28N-03W-18	NL	60	859
	19669	28N-01W-09	NL	870	510
	20118	28N-01W-08	NL	1645	860
	21514	29N-02W-13	--	1500	710
	21516	29N-02W-11	--	1660	100
	21591	29N-02W-23	1636	1675	957
	21595	29N-01W-07	--	1655	808
	21908	27N-03W-14	1900	1970	914
	21915	27N-04W-01	1993	2045	1030

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Shannon	21974	27N-03W-08	NL	1530	918
	22097	27N-03W-17	1892	1910	921
	0-16	28N-04W-25	--	1698	999
	0-17	28N-02W-13	NL	1440	600
	0-18	28N-01W-07	--	1400	530
	0-41	31N-02W-08	1422	--	1220
	0-42	31N-02W-17	1447	--	1210
	0-43	31N-03W-25	1611	--	1235
	0-45	31N-02W-31	1405	--	1010
	0-47	32N-02W-03	1356	--	1200
	0-50	31N-03W-01	1205	--	1040
	0-51	31N-03W-11	1423	--	1290
	0-54	31N-03W-04	1058	--	1000
	0-55	31N-03W-04	1201	--	1150
	0-57	31N-02W-18	1447	--	1270

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Shannon	0-60	32N-04W-12	1330	--	1210
	0-61	31N-03W-36	1477	--	1170
	0-62	31N-04W-28	1125	--	750
	0-64	32N-03W-29	1111	--	975
	0-65	32N-03W-32	1094	--	980
	0-66	32N-03W-33	1079	--	1020
	0-67	32N-03W-21	1337	--	1180
Stoddard	8742	25N-11E-03	NL	4572	300
St. Francois	1680	35N-05E-02	--	675	967
	2275	36N-04E-22	--	805	940
	2276	36N-04E-15	NL	485	1000
	2331	36N-04E-14	NL	495	859
	4718	36N-05E-25	305	638	969
	5254	35N-05E-02	355	658	888
	5447	34N-04E-16	NL	70	1097

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
St. Francois	7450	34N-06E-10	NL	60	908
	7458	35N-05E-17	--	35	925
	8524	35N-04E-31	--	355	1063
	9244	35N-05E-02	400	760	885
	11887	33N-02E-33	NL	345	724
	0-73	36N-05E-06	--	850	791
St. Genevieve	15384	36N-07E-36	215	--	835
	20720	36N-06E-06	230	--	930
	0-1	35N-08E-18	460	--	777
	0-2	35N-07E-25	455	--	789
	0-72	35N-07E-15	--	406	--
St. Louis	12528	47N-07E-07	NL	3218	585
Texas	2879	33N-09W-14	1575	--	1177
	0-3	32N-10W-25	1420	1565	961
Taney	0-20	24N-20W-15	--	1870	750

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Vernon	1861	37N-32W-31	NL	1255	803
	8617	37N-32W-31	NL	1440	800
	23680	37N-30W-02	1660	1880	770
Washington	2128	37N-02E-11	925	--	877
	2309	36N-03E-14	780	875	897
	8286	36N-02E-36	NL	25	914
	9374	36N-01E-07	NL	1080	1174
	9375	36N-01W-01	NL	830	1092
	9379	36N-01E-07	NL	1000	1086
	9381	36N-01E-17	NL	735	1165
	10680	37N-02E-11	980	--	964
	10940	37N-01W-30	1290	--	761
	12287	38N-01E-18	NL	445	1000
	12306	38N-01E-31	NL	1115	1130
	12316	38N-01E-18	NL	1093	985

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Washington	12317	38N-01E-29	NL	1045	1118
	12318	38N-01E-19	NL	1065	1112
	12319	38N-01E-20	NL	1132	960
	12324	38N-01E-28	--	1095	1070
	19687	38N-01E-12	--	1365	805
	19688	38N-01E-01	1003	1173	767
	19964	37N-02E-32	1215	1285	1072
	20154	35N-01W-16	NL	490	1077
	20182	35N-01W-16	NL	480	1009
	20353	35N-01W-11	755	--	1150
	20366	38N-02E-07	--	1250	713
	21066	38N-02E-01	950	--	778
	22394	38N-03E-27	970	1258	873
Wayne	2743	28N-05E-28	NL	125	413
	3185	30N-05E-19	NL	315	620

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Wayne	22751	27N-04E-26	NL	2051	510
	22812	27N-03E-10	NL	2410	720
	0-6	28N-04E-06	NL	1125	657
	0-7	28N-04E-17	--	1800	659
	0-8	29N-05E-21	NL	765	400
		IOWA			
Page	Wilson #1	68N-37W-25	3555*	3570	967
Taylor	Long #1	68N-34W-20	NL	3750	1097
		ILLINOIS			
Madison	Kircheis #S-1	03N-06W-27	--	5011	504
Monroe	Theobald #A-15	01S-10W-35	--	2759	666
Pike	Campbell #1	04S-05W-15	--	3204	716
	Munford #1-21	05S-04W-21	--	2221	812

*Mt. Simon

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
		OKLAHOMA			
Craig	CR6-1	28N-20E-31	--	1692	859
	CR6-2	28N-20E-19	--	1493	838
	CR6-3	26N-19E-04	--	2102	835
	CR6-4	26N-21E-12	--	1769	750
	CR6-5	24N-21E-20	--	1715	856
Deleware	DR-1	23N-25E-17	--	1019	1045
	DR-2	20N-22E-18	--	2184	1019
Ottawa	OT-1	28N-22E-24	--	1045	798
	OT-2	29N-23E-23	--	1762	833
	OT-3	29N-22E-13	--	1185	822
	OT-4	28N-22E-08	--	291	770
	OT-5	28N-22E-08	--	345	775
	OT-6	29N-23E-20	--	1735	832
	OT-7	29N-23E-19	--	1617	833

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
		NEBRASKA			
Cass	#1 Roffner	11N-13E-05	--	1565	1185
	#1 Schroeder	11N-12E-26	--	1567	1145
	#1 Sporer	11N-13E-08	--	1345	1140
	#11 Stratigraphic	10N-12E-28	--	1480	1216
Johnson	#1 Bartels	04N-10E-33	--	1280	1378
	#1 Dysart	04N-10E-12	--	1017	1320
	#4 Strat. (Shact)	06N-12E-06	--	1150	1024
	#5 Strat. (Brehm)	05N-12E-05	--	1015	1187
	#6 Strat. (Broody)	04N-12E-04	--	808	1266
	#7 Strat. (Broody)	05N-12E-20	--	853	1240
	#8 Strat. (Hertz)	05N-12E-08	--	978	1251
	#9 Strat. (Minor)	05N-12E-16	--	877	1244
Nemaha	#1 Beason	06N-13E-21	--	3015	1058
	#1 Casey	05N-13E-07	--	3302	1165

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Nemaha	#1 Snyder	06N-15E-34	--	3500	942
Otoe	#1 Brick Plant	08N-14E-10	--	2847	932
	#1 Reitsch	08N-10E-01	--	1800	1115
	#1 Ritter	07N-12E-25	--	2529	987
	#1 Strat. (Cameron)	07N-10E-11	--	1795	1175
	#2 Strat. (Hopp)	07N-11E-22	--	1303	1031
	#10 Strat. (Strout)	09N-12E-03	--	1148	1172
	#11 Strat. (Schutz)	09N-12E-07	--	1630	1238
	#1 Wendlin	07N-12E-21	--	1144	1005
Pawnee	#1"A" Honzerer	02N-12E-26	--	690	1173
	#1 Bernadt	03N-11E-31	--	675	1198
	#1 Blecha	02N-12E-15	--	605	1093
	#1 Church	01N-12E-25	--	532	1027
	#1 Clark	02N-11E-12	--	750	1087
	#1 Couault	02N-12E-17	--	725	1209

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Pawnee	#1 Dahlke	03N-12E-14	--	665	1161
	#1 Farwell	01N-12E-28	--	610	1101
	#1 Loch	01N-10E-31	--	1093	1494
	#1 Miller	03N-12E-29	--	585	1033
	#1 Pesek	01N-12E-13	--	512	1005
	#1 Small	02N-10E-34	--	871	1353
	#1 Wilson	01N-10E-04	--	899	1343
Richardson	#1 Albin	01N-14E-26	--	3500	1034
	#1 Berg-Shubert	03N-16E-08	--	4041	1061
	#1 Boomgarn	03N-13E-28	--	2082	1127
	#1 Boose et. al.	02N-17E-35	--	4031	1046
	#1 Edelman	01N-14E-14	--	3480	1013
	#1 Funk	02N-14E-32	--	3555	1063
	#1 Haight	01N-13E-30	--	695	1145
	#1 Harlow	01N-13E-32	--	750	1112

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Richardson	#1 Horalek	02N-13E-29	--	1821	1143
	#1-A Hustead	02N-16E-02	--	3930	1089
	#1 Kalous	02N-13E-05	--	1092	1008
	#1 Kalous Strat.	02N-13E-06	--	1820	1053
	#4 Kauas	01N-14E-02	--	3277	943
	#1 Kotouc	02N-13E-24	--	3620	1041
	#3 Lewis-Shubert	03N-16E-04	--	4072	1099
	#1 Lyle Wittwer	01N-14E-17	--	3404	1002
	#A-3 Miles	01N-14E-11	--	3284	951
	#A-4 Miles	01N-14E-11	--	3272	949
	#1 Munson Strat.	03N-13E-31	--	1655	1080
	#1 Ogle	01N-14E-09	--	3419	1071
	#1 Pullman Cattle	01N-15E-30	--	3960	1084
	#1 Schmidt	03N-14E-11	--	3814	1059
	#1 Shellenberger	01N-14E-23	--	3556	1153

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Richardson	#1 Stalder	01N-13E-14	--	3600	1163
	#1-A State Bank	01N-14E-10	--	3289	943
	#29A-2-13 Strat.	02N-13E-29	--	1821	1140
	#1 Whitney Strat.	03N-13E-30	--	991	1113
	#1 Tablerock	02N-13E-30	--	1466	1089
		KANSAS			
Allen	Dalton Deep Test	02S-19E-34	--	2145	1030
	Iola Deep Test	24S-18E-26	--	2157	975
Anderson	#1 Wiggins	23S-17E-13	--	2285	1025
Atchison	#1 Oak Mills	07S-21E-13	--	2850	795
Bourbon	#1 Burney	25S-25E-21	--	1860	760
	#1 Stevenson	26S-24E-16	--	1810	933
	#1 Wierner	26S-23E-25	--	1826	950
Brown	#1 Butterfield	01S-15E-08	--	4016	1200
Chautauqua	#1 Blecha	32S-13E-05	--	2645	988

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Chautauqua	#1 Kucher	33S-12E-34	--	2794	808
	#1 Clark	33S-21E-13	--	1906	825
	#4 Fee	33S-23E-13	--	1771	901
	#1 Forkner	33S-23E-17	--	1870	924
	#1 Harley	31S-22E-30	--	1845	905
Crawford	#1 Gobl	28S-25E-20	--	1838	945
Douglas	#1 Emmett	14S-18E-06	--	2826	1077
	#1 Stanley	14S-21E-03	--	2463	931
Elk	#1 Osborn	31S-11E-08	--	2953	1031
Franklin	#6 Thompson	17S-20E-11	--	2295	992
Greenwood	#2"D" Beal	23S-11E-21	--	3115	1169
Jefferson	#1 Winchester	09S-19E-13	--	3085	1073
Johnson	#1 Harrington	14S-22E-12	--	2047	1026
	#1 James	13S-25E-08	--	2273	861
Labette	#1 Bradford	31S-19E-05	--	2155	957

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Labette	#3 Wackerle	35S-19E-01	--	1318	976
	#1 Wert	31S-21E-17	--	1886	856
Leavenworth	#1 Kirk	07S-22E-35	--	2745	777
	#1 McGreevy	10S-22E-24	--	2663	961
Lyon	#1 Day	16S-11E-16	--	3111	1393
	#1 Mason	18S-12E-24	--	3177	1207
Marshall	#1 Brosa	04S-10E-16	--	1065	1250
	#1 Fisher	04S-10E-09	--	1110	1239
	#1 Olson	03S-10E-15	--	924	1290
Miami	#1 City Dump	18S-22E-12	--	2085	846
	#1 Lee	16S-23E-16	--	2283	894
	#1 Paola	17S-23E-16	--	2250	900
Montgomery	#1 Beal	33S-14E-12	--	2536	875
	#1 Carter	32S-14E-23	--	2400	818
	#10 Cement Plant	33S-16E-05	--	1344	781

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Montgomery	#1 Gillam	35S-15E-04	--	2355	750
	#1 Gressell	32S-16E-08	--	2320	765
	#1 Hadden-Wheeler	34S-15E-04	--	2472	820
	#1 Hatch	35S-14E-07	--	2799	760
	#1 Meredith	34S-17E-15	--	2290	750
	#1 Miller	33S-17E-33	--	2155	720
	#1 Pocock	34S-13E-11	--	270	758
	#1 Rail (Woody)	33S-15E-07	--	2535	852
	#1 Schumaker	35S-13E-11	--	2806	731
	#1 Smith	31S-16E-27	--	2290	809
	#1 Vitts	32S-16E-07	--	2330	824
	#1 Vitts	32S-16E-18	--	2320	824
Nemaha	#1 Bailey	04S-13E-34	--	3918	1296
	#1 Griffiths	05S-13E-23	--	2971	1342
	#1 Hutfles	03S-13E-25	--	2972	1302

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Nemaha	#2 Koch-Ranson	02S-14E-28	--	3949	1289
	#1 Lamparter	02S-14E-03	--	3940	1326
	#1 Murdock	02S-13E-16	--	790	1292
	#1 Strahm	02S-14E-13	--	3929	1254
	#1 Seneca	02S-12E-33	--	586	1174
	#1 Seneca	03S-11E-19	--	705	1218
	#1 Swart	03S-13E-26	--	2438	1284
Neosho	#1 Arnett	30S-18E-34	--	2235	945
	#1 Kaney	27S-18E-22	--	2113	900
Osage	#1 Badger	15S-16E-04	--	2740	1174
	#1 Hyde	16S-15E-14	--	2874	1133
	#1 Miles	14S-14E-23	--	3085	1224
	#1 Neill	17S-17E-08	--	2540	1014
Pottawatomie	#1 Ault	09S-11E-05	--	2974	1077
	#1 Bairow	08S-10E-26	--	1837	1180

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Pottawatomie	#1 Browning	08S-12E-08	--	3613	1224
	#1 Brunner	09S-10E-36	--	2985	973
	#12-1 Corehole	08S-10E-07	--	1878	1423
	#12-2 Corehole	07S-10E-29	--	1707	1395
	#12-3 Corehole	08S-10E-01	--	2003	1125
	#12-4 Corehole	07S-10E-01	--	1449	1365
	#12-6 Corehole	07S-10E-04	--	1715	1475
	#1 Handley	07S-12E-06	--	3014	1266
	#1 Hartwick	07S-11E-19	--	1434	1268
	#1 Johnson	08S-12E-29	--	3457	1128
	#1 Kelly	07S-10E-25	--	1406	1173
	#1 McFarland	08S-11E-14	--	3486	1296
	#1 Miller	08S-12E-22	--	3480	1154
	#1 Rezac	09S-12E-07	--	3605	1257
	#1 Rokes	06S-11E-34	--	906	1171

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Shawnee	#1 Heiland	10S-13E-06	--	3320	1115
	#1 Hummer	11S-16E-14	--	3005	949
	#1 Ripley	12S-16E-12	--	3005	1016
Wabaunsee	#1 Henderson	13S-12E-15	--	3428	1172
	#1 Martin	13S-12E-35	--	3594	1334
	#1 Thoewe	13S-10E-02	--	3280	1113
Wilson	#1 Birk	30S-17E-21	--	2297	945
	#1 McFadden	27S-16E-26	--	2366	1015
	#1 Neodesha	30S-16E-19	--	2277	804
	#3 Smith	29S-15E-10	--	2203	995
Woodson	#1 Byers	25S-14E-26	--	2490	989
	#1 Eades	25S-15E-10	--	2590	1050
	#2 Newbold	25S-16E-29	--	2386	1070
	#1 Solomon	26S-17E-29	--	2258	1026
	#1 Stevenson	24S-14E-05	--	2821	1140

Appendix 1 - continued

County	Well number	Location	Depth to top of Lamotte	Depth to top of Precambrian	Ground elevation
Woodson	#1 Stockerbrand	25S-15E-17	--	2592	1104
	#1 Wix	25S-15E-32	--	2562	1008
	#1 Wright	25S-17E-03	--	1952	1045
Wyandotte	#1 Swift	11S-25E-15	--	2327	747

APPENDIX 2

SAMPLE DESCRIPTION

Well number	Footage From-To		Description	Formation
2088	1425	1520	Quartz sandstone, gray-buff, fine to medium grained, light red stain on quartz grains.	Lamotte
	1520	1530	Shale, red, abundant hematite.	
	1530	1570	Quartz sandstone, medium to coarse grained, kaolin in pore space, red hematite stain throughout, argillaceous toward base.	
	1575	1585	Arkose, coarse-grained, red stained with shale, red.	
2128	--	925	Dolomite, gray, silty, argillaceous, glauconitic.	Bonneterre
	925	--	Quartz sandstone, white, fine-to medium grained.	Lamotte
2246	1420	1445	Quartz sandstone, gray, fine grained, glauconitic, dolomitic.	Bonneterre
	1445	1495	Quartz sandstone, buff, fine grained, kaolin in pore space.	Lamotte
	1495	1590	Quartz sandstone, red hematite stain throughout.	
	1590	1600	Shale, siltstone, red hematite stain.	
	1600	1660	Quartz sandstone, fine grained, red hematite stain throughout.	
	1660	1700	Quartz sandstone, buff to gray, bimodal distribution - large, coarse, angular fragments and fine to medium grained.	

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
	1700	1750	Arkose, coarse grained, angular red hematite stain throughout.	
	1750	--		Precambrian
2309	780	875	Quartz sandstone, fine to medium grained, rounded alternating open pores, silt or kaolin filling pores.	Lamotte
	875	--		Precambrian
2341	1845	1900	Quartz sandstone, gray, floating subrounded, small amount of glauconite present.	Bonneterre
	1900	2050	Quartz sandstone, buff, very light secondary red stain on quartz grains.	Lamotte
	2050	2145	Quartz sandstone, red hematite stain throughout.	
	2145	2190	Arkose, red, coarse grained, angular, dirty.	Precambrian
2879	1555	1575	Quartz sandstone, gray, gray dolomite.	Bonneterre
	1575	1600	Quartz sandstone, buff, fine to medium grained, alternating open and kaolin filled pores.	Lamotte
	1600	1610	Quartz sandstone, buff to gray, very fine grained.	
	1610	1630	Quartz sandstone, buff, fine to medium grained, kaolin in pore spaces.	
	1630	1645	Quartz sandstone, red hematite stain throughout.	

Well number	Footage From-To		Description	Formation
	1645	--	Subarkose, red hematite stain throughout.	Lamotte
3061	2105	2155	Quartz sandstone, gray, fine to medium grained, with dolomite, gray.	Bonneterre
	2155	2225	Quartz sandstone, fine to medium grained, light secondary red stain on quartz grains, washed appearance.	Lamotte
	2225	2275	Quartz sandstone, medium to coarse grained, light secondary red stain.	
	2275	--		Precambrian
4718	215	305	Quartz sandstone, buff to gray, dolomite, buff to gray, glauconitic.	Bonneterre
	305	420	Quartz sandstone, buff, fine to medium grained, open pores.	Lamotte
	420	450	Quartz sandstone, buff, large, yellow grains present, kaolin on pores.	
	450	515	Quartz sandstone, buff, fine to medium grained, kaolin in pores.	
	515	525	Quartz sandstone, red hematite stain throughout.	
	525	585	Quartz sandstone, buff, fine to medium grained, kaolin in pores.	
	585	638	Subarkose, fine to medium grained, red hematite stain throughout.	

Appendix 2 - continued

Well number	Footage From	Footage To	Description	Formation
	638	--		Precambrian
5254	280	355	Quartz sandstone, buff to gray, fine to medium grained, dolomite, gray, glauconitic.	Bonneterre
	355	420	Quartz sandstone, buff to white, fine grained, open pore spaces.	Lamotte
	420	648	Quartz sandstone, buff, fine grained, kaolin in pores.	
	648	658	Subarkose, buff to brown.	
	658	--		Precambrian
5354	1220	--	Quartz sandstone, buff, silt in pore spaces.	Lamotte
8526	1250	1310	Quartz sandstone, fine grained, gray-green, dolomite, gray, glauconitic.	Bonneterre
	1310	1380	Quartz sandstone, buff, fine grained, interbedded, open and kaolin filled pores.	Lamotte
	1380	1400	Quartz sandstone, medium grained, primary red hematite stain.	
	1400	--	Samples missing	
9224	295	400	Quartz sandstone, buff to gray, fine to medium grained, dolomite, buff to gray, glauconitic.	Bonneterre

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
9224	400	525	Quartz sandstone, buff to white, fine to medium grained, open pores.	Lamotte
	525	565	Quartz sandstone, buff to white, fine to medium grained, kaolin in pore spaces.	
	565	760	Quartz sandstone becoming subarkosic toward base, fine to medium grained, red hematite stain throughout.	
	760	--		Precambrian
10680	--	980	Quartz sandstone, argillaceous, arenaceous, dolomite, gray.	Bonneterre
	980	--	Quartz sandstone, white, fine to medium grained.	Lamotte
10940	1275	1290	Quartz sandstone, gray, bimodal distribution - medium and rounded, dolomite, gray with trace of glauconite.	Bonneterre
	1290	--	Quartz sandstone, buff, fine to medium grained	Lamotte
11294	2780	2800	Quartz sandstone, gray, floating, dolomite, gray, some shale.	Bonneterre
	2800	2940	Quartz sandstone, buff, fine to medium grained, light red stain on quartz grains, some frosting, subrounded.	Lamotte
	2940	2985	Arkose, red to gray, coarse grained, shale, red to black.	
	2985	--		Precambrian

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
12328	--	1760	Quartz sandstone, buff to gray, pyritic dolomite, gray, glauconitic.	Bonneterre
	1760	1795	Quartz sandstone, white to buff, fine to medium grained, subrounded, open pores.	Lamotte
	1795	1900	Quartz sandstone, white to buff, fine to medium grained, subrounded, kaolin in pores.	
	1900	1960	Arkose, fresh, angular.	
	1960	--		Precambrian
12590	675	--	Quartz sandstone, buff, fine to medium grained, alternating open and kaolin filled pore spaces.	Lamotte
15384	140	214	Quartz sandstone, buff to gray, bimodal distribution - fine and large rounded, floating, dolomite, buff to gray, glauconitic.	Bonneterre
	214	215	Arenaceous shale, black.	
	215	--	Quartz sandstone, white to buff, fine to medium grained, open pore spaces.	Lamotte
18139	1885	1910	Quartz sandstone, buff to white, fine to medium grained, subrounded, open pores.	
	1910	1925	Quartz sandstone, buff to white, fine to medium grained, subrounded, kaolin in pores.	

Appendix 2 - continued

Well number	Footage From-To	Description	Formation
18139	1925 1960	Quartz sandstone, fine grained, bright red primary hematite staining, subangular.	Lamotte
	1960 2015	Quartz sandstone, buff, fine grained, kaolin in pores.	
	2015 2023	Arkose, red to gray, coarse grained, red shale.	
	2023 --		Precambrian
18839	1105 --	Quartz sandstone, buff, medium grained, subrounded, open pore spaces.	Lamotte
19688	945 1003	Quartz sandstone, gray, fine to medium grained, shale partings and mica, melted sugary texture, glauconitic, dolomitic.	Bonneterre
	1003 1172	Quartz sandstone, white to buff, fine to medium grained, kaolin in pore spaces.	Lamotte
	1172 1173	Arkose	
	1173 --		Precambrian
19703	875 --	Quartz sandstone, very white, fine to medium grained, open pores.	Lamotte
19964	1100 1215	Quartz sandstone, gray, fine and medium grains, well rounded, dolomitic.	Bonneterre
	1215 1250	Quartz sandstone, white to buff, fine to medium grained, open pore spaces.	Lamotte

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
19964	1250	1265	Quartz sandstone, white to buff, fine to medium grained, alternating open and kaolin filled pore spaces.	Lamotte
	1265	1285	Quartz sandstone, red hematite stain throughout, becomes argillaceous and arenaceous toward base of hole.	
	1285	--		Precambrian
20254	780	--	Quartz sandstone, medium red hematite stain throughout, kaolin in pore spaces.	Lamotte
20353	--	755	Quartz sandstone, buff to gray, dolomitic, glauconitic.	Bonneterre
	755	--	Quartz sandstone, very white.	Lamotte
20363	674.9	675	Shale, black, pyritic.	
	675	--	Quartz sandstone, buff, fine to medium grained, open pore spaces.	
20465	1730	1765	Quartz sandstone, gray, medium grained, round, floating, dolomitic.	Bonneterre
	1765	1830	Quartz sandstone, buff, light red stain on quartz grains throughout.	Lamotte
	1830	--	Arkose, coarse grained, red hematite stain throughout, angular.	

Well number	Footage From	To	Description	Formation
20720	215	230	Quartz sandstone, gray, bimodal distribution - fine and medium to large grained, well rounded, argillaceous, arenaceous, dolomite, gray, glauconitic.	Bonneterre
	230	240	Shale, red hematite stain.	
	240	--	Quartz sandstone, buff, fine to medium grained, kaolin in pore spaces.	Lamotte
21066	900	950	Quartz sandstone, gray, bimodal distribution - fine and extra fine, floating dolomite, gray, glauconitic.	Bonneterre
	950	--	Quartz sandstone, buff to white, fine to medium grained, open pore spaces.	Lamotte
21245	1095	1250	Quartz sandstone, buff, fine to medium grained, open pore spaces.	
	1250	1300	Quartz sandstone, buff, fine to medium grained, kaolin in pore spaces.	
	1300	1420	Quartz sandstone, fine to medium grained, red hematite stain throughout, sorting poor toward base.	
	1420	1450	Subarkose, red, coarse grained, dirty.	
	1450	--		Precambrian
21324	1070	1191	Quartz sandstone, buff, fine to medium grained, alternating open pore spaces and kaolin in pore spaces.	Lamotte

Well number	Footage From-To		Description	Formation
21324	1191	1200	Shale, red hematite stain to almost pure hematite.	Lamotte
	1200	1250	Quartz sandstone, red hematite stain throughout, kaolin in pore spaces.	
	1250	1255	Shale, red hematite stain to almost pure hematite.	
	1255	1274	Quartz sandstone, red hematite stain throughout, kaolin in pore spaces.	
	1274	1326	Arkose, coarse grained, red, sorting poor becoming poorer to base of section.	
	1326	--		Precambrian
21326	1310	--	Quartz sandstone, white, medium grained, subrounded, open pores.	Lamotte
21385	1515	--	Quartz sandstone, white, fine to medium grained, subrounded, kaolin in pore spaces.	
21521	1320	1340	Quartz sandstone, white, fine to medium grained, subrounded, alternating open and kaolin filled pore spaces.	
	1340	1400	Quartz sandstone, white, fine to medium grained, subrounded, kaolin in pore spaces.	
	1400	1405	Subarkose, reddish brown, medium to coarse grained, angular to subangular.	
	1405	--		Precambrian

Appendix 2 - continued

Well number	Footage From-To	Description	Formation
21589	1585 1630	Sandstone, gray, fine grained, glauconitic, dolomite, gray.	Bonneterre
	1630 1655	Quartz sandstone, buff, fine grained, open pore spaces.	Lamotte
	1655 1670	Quartz sandstone, buff, very fine grained, open pore spaces.	
	1670 1703	Quartz sandstone, buff, fine grained, kaolin in pore spaces.	
	1703 1736	Subarkose, red fine grained.	
	1736 --		Precambrian
21591	1615 1635	Subarkose, brown to red, fine to medium grained, poor sorting, dolomite, gray, glauconitic.	Bonneterre
	1635 1675	Subarkose, fine to coarse grained, red hematite stain, very poor sorting.	Lamotte
	1675 --		Precambrian
21599	650 --	Quartz sandstone, white to buff, fine to medium grained, subrounded, open pore spaces.	Lamotte
21765	1240 1265	Quartz sandstone, gray, fine grained, rounded, dolomite, gray, glauconitic.	Bonneterre
	1265 1465	Bad samples - appears typical Lamotte	Lamotte

Appendix 2 - continued

Well number	Footage From-To	Description	Formation
21765	1465 --		Precambrian
21908	1900 1938	Subarkose, very fine grained, trace of dolomite, gray, texture like melted sugar.	Bonneterre
	1938 1948	Quartz sandstone, white, fine to medium grained, open pore spaces.	Lamotte
	1948 1949	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces, ball of glauconitic material about 1948.5.	
	1949 1960	Quartz sandstone, white, fine to medium grained, open pore spaces.	
	1960 1970	Subarkose, buff to red.	
	1970 --		Precambrian
21915	1955 1993	Sandstone, gray, fine and medium grained, floating, round.	Bonneterre
	1993 1994	Shale, black, pyritic.	
	1994 2010	Sandstone, fine grained, red hematite stain throughout.	Lamotte
	2010 2045	Subarkose, medium grained, subangular, red hematite stain throughout.	
	2045 --		Precambrian

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
22002	1585	1650	Dolomite, gray-green, sandstone, fine grained, glauconitic.	Bonneterre
	1650	--	Quartz sandstone, buff, fine grained, open pore spaces.	Lamotte
22097	1860	1892	Dolomite, gray, sandstone, gray, subrounded, glauconitic.	Bonneterre
	1892	1909	Sandstone, buff to gray, fine grained, sugary texture, alternating open and kaolin filled pore spaces.	Lamotte
	1909	1910	Arkose.	
	1910	--		Precambrian
22394	895	970	Dolomite, gray, sandstone, gray, fine to medium grained, well rounded, glauconitic.	Bonneterre
	970	1120	Quartz sandstone, buff to white, fine to medium grained.	Lamotte
	1120	1170	Quartz sandstone, buff to white, bimodal distribution - fine to medium grained and coarse grained, some large yellow grains of apatite.	
	1170	1258	Quartz sandstone, red hematite stain throughout.	
	1258	--		Precambrian

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
23680	1660	1880	Sample bad, faint red stains on quartz grains which has washed appearance.	Lamotte
	1880	--		Precambrian
24670	1525	1590	Sandstone, fine grained, arenaceous, glauconitic, with dolomite, gray, shale parting, black, pyritic.	Bonneterre
	1590	1640	Quartz sandstone, buff, fine to medium grained, open pore spaces.	Lamotte
	1640	1743	Quartz sandstone, buff, fine to medium grained, kaolin in pore spaces.	
	1743	1791	Subarkose, medium grained, red hematite stain throughout.	
	1791	1806	Quartz sandstone, gray, coarse grained, subangular.	
	1806	1825	Arkose, red, coarse grained, angular.	
	1825	--		Precambrian
24490	1365	1445	Quartz sandstone, fine grained, floating, with dolomite, gray.	Bonneterre
	1445	1485	Quartz sandstone, buff, fine grained, open pore spaces.	Lamotte
	1485	1540	Quartz sandstone, buff, fine to medium grained, kaolin in pore spaces.	

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
24490	1540	1574	Quartz sandstone, buff, medium grained, kaolin in pore spaces.	Lamotte
	1574	1645	Subarkose, medium to coarse grained, red hematite stain throughout.	
	1645	--		Precambrian
24544	1520	1593	Quartz sandstone, fine to medium grained, glauconitic, small amount of carbonate, many small shale partings.	Bonneterre
	1593	1638	Quartz sandstone, buff, fine to medium grained, open pore spaces.	Lamotte
	1638	1730	Quartz sandstone, buff, fine to medium grained, kaolin in pore spaces.	
	1730	1805	Subarkose, coarse grained, red hematite stain throughout.	
	1805	1818	Quartz sandstone, buff, fine to medium grained.	
	1818	1825	Arkose, red, coarse grained, subangular.	
	1825	--		Precambrian
27234	1430	--	Quartz sandstone, buff, fine grained, open pore spaces, subrounded.	Lamotte
26243	1505	--	Quartz sandstone, buff, fine grained, open pore spaces, subrounded.	

Well number	Footage From-To		Description	Formation
26254	1865	--	Quartz sandstone, buff, fine grained, open pore spaces, subrounded.	Lamotte
O-1	425	455	Quartz sandstone, gray to buff, arenaceous, dolomitic.	Bonneterre
	455	--	Quartz sandstone, white to buff, fine to medium grained.	Lamotte
O-2	385	455	Quartz sandstone, gray to buff, arenaceous, dolomitic.	
	455	--	Quartz sandstone, white to buff, fine to medium grained.	
O-4	1135	1160	Quartz sandstone, gray to buff, arenaceous, dolomitic.	Bonneterre
	1160	--	Quartz sandstone, buff, fine to medium grained, kaolin in pore spaces.	Lamotte
O-5	1590	1620	Quartz sandstone, gray, arenaceous, dolomitic.	Bonneterre
	1620	--	Quartz sandstone, white, fine to medium grained.	Lamotte
O-29	--	924	Dolomite, gray, argillaceous, arenaceous.	Bonneterre
	924	--	Quartz sandstone, white to buff, fine to medium grained, open pore spaces.	Lamotte
O-30	--	1115	Quartz sandstone, gray, medium grained, cross bedded, dolomitic, glauconitic, undulating shale partings.	Bonneterre
	1115	1122	Quartz sandstone, white, medium grained, subrounded, open pore spaces.	Lamotte

Appendix 2 - continued

Well number	Footage From-To	Description	Formation
0-30	1122 --	Quartz sandstone, white, medium grained, subrounded, kaolin in pore spaces.	Lamotte
0-31	-- 979	Dolomite, gray, arenaceous, abundant glauconite, trace of sand, very thin black band of shale at 979.	Bonneterre
	979 --	Quartz sandstone, white, fine to medium grained, alternating open and kaolin filled pore spaces.	Lamotte
0-32	-- 1146	Dolomite, gray, abundant glaudonite, pyrite, trace sand.	Bonneterre
	1146 --	Quartz sandstone, white, fine to medium grained, open pore spaces, some trace kaolin.	Lamotte
0-33	-- 1271	Dolomite, gray, abundant glauconite, pyrite, trace sand.	Bonneterre
	1271 --	Quartz sandstone, white, fine to medium grained, open pore spaces, some trace kaolin.	Lamotte
0-34	-- 1191	Dolomite, gray, arenaceous, glauconitic.	Bonneterre
	1191 --	Quartz sandstone, white, subrounded, kaolin in pore spaces.	Lamotte
0-35	-- 1288	Dolomite, gray, arenaceous, at 1288 an inch shale zone, black, pyritic.	Bonneterre
	1288 --	Quartz sandstone, white, fine to medium grained, subrounded, kaolin in pore spaces.	Lamotte

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
0-36	--	1474	Dolomite, gray, quartz sandstone, glauconitic, at 1474 is shale, black, pyritic.	Bonneterre
	1474	1476	Quartz sandstone, white, fine to medium grained, sub-rounded, open pore spaces.	Lamotte
	1476	1480	Quartz sandstone, white, fine to medium grained, sub-rounded, interbedded open pore spaces and kaolin in pore spaces.	
0-37	--	1419	Dolomite, gray, abundant glauconite at 1419, one inch shale zone, undulating.	Bonneterre
	1419	--	Quartz sandstone, white, fine to medium grained, open pore spaces.	Lamotte
0-38	--	1370	Quartz sandstone, gray, with dolomite, gray, glauconitic.	Bonneterre
	1370	--	Quartz sandstone, white, fine to medium grained, open pore spaces.	Lamotte
0-39	--	1489	Dolomite, gray, trace of glauconite, at 1489 shale, black, pyritic.	Bonneterre
	1489	--	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-40	--	1574	Dolomite, gray, glauconitic, trace sand.	Bonneterre
	1574	--	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte

Well number	Footage From-To	Description	Formation
0-41	-- 1422	Dolomite, gray, clean, minor trace of glauconite.	Bonneterre
	1422 --	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-42	-- 1447	Dolomite, gray, clean, trace of galena.	Bonneterre
	1447 --	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-43	-- 1161	Dolomite, gray, clean, becoming slightly arenaceous with sugary texture at contact. At contact thin, black shale, undulating, pyritic.	Bonneterre
	1161 --	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-45	-- 1405	Dolomite, gray, arenaceous, glauconitic, trace of galena mineralization, undulating shale bands. At 1405 about 2 inch shale zone, black, pyritic.	Bonneterre
	1405 --	Quartz sandstone, white, fine to medium grained, sub-rounded, kaolin in pore spaces.	Lamotte
0-46	-- 1121	Dolomite, gray, dirty, wavy shale bands, glauconite at 1121 about 1 inch thick, shale, black, pyritic.	Bonneterre
	1121 --	Quartz sandstone, white, fine to medium grained, open pore spaces.	Lamotte

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
0-47	--	1356	Dolomite, gray, arenaceous, dirty, wavy shale band, glauconitic, trace of galena mineralization.	Bonneterre
	1356	--	Quartz sandstone, white, fine to medium grained, open pore spaces.	Lamotte
0-48	--	1418	Dolomite, gray, argillaceous, many wavy shale partings, very glauconitic, at 1418 about 2 inch black shale, pyritic.	Bonneterre
	1418	--	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-49	--	1094	Dolomite, gray, clean, trace glauconite, many wavy shale bands throughout.	Bonneterre
	1094	--	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-50	--	1205	Dolomite, gray, trace sand, shale and glauconite, many wavy shale bands throughout.	Bonneterre
0-51	--	1422	Dolomite, gray, glauconitic, trace of sand.	
	1422	1423	Gradation from Bonneterre to Lamotte	
	1423	--	Quartz sandstone, white, fine to medium grained, open pore spaces.	Lamotte
0-54	--	1058	Dolomite, gray, arenaceous, fine, glauconitic.	Bonneterre

Well number	Footage From-To		Description	Formation
0-54	1058	--	Quartz sandstone, white, fine to medium grained, open pore spaces.	Lamotte
0-55	--	1201	Dolomite, gray, sandstone, gray, fine to medium grained, glauconitic.	Bonneterre
	1201	--	Quartz sandstone, white, coarse grained open pore spaces.	Lamotte
0-56	--	1507	Quartz sandstone, gray, fine grained, with dolomite, gray, at 1507 about 1 inch shale band, black, pyritic.	Bonneterre
	1507	--	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-57	--	1447	Quartz sandstone, gray, with dolomite, gray, trace of galena mineralization.	Bonneterre
	1447	--	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-59	--	1477	Dolomite, gray, very argillaceous, slightly glauconitic.	Bonneterre
	1477	--	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-60	--	1330	Dolomite, gray, argillaceous, glauconitic, many wavy black shale bands, at 1330 a 3 inch shale band, black, pyritic, trace of galena mineralization.	Bonneterre

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
0-60	1330	--	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-61	1935	1963	Dolomite, gray, glauconitic, dirty, wavy shale bands.	Bonneterre
	1963	1964	Shale, black, pyritic.	
	1964	1986	Dolomite, gray, glauconitic, dirty, wavy shale bands, at 1986 about 1 inch shale, black, pyritic.	
	1986	2024	Quartz sandstone, white, fine to medium grained, subrounded, kaolin in pore spaces.	Lamotte
	2024	2060	Quartz sandstone, white, fine to medium grained, subrounded, kaolin in pore spaces, red hematite stain throughout.	
	2060	2078	Quartz sandstone, white, fine to medium grained, subrounded, kaolin in pore spaces.	
	2078	2120	Quartz sandstone, very bright red to purple hematite stains throughout.	
	2120	2197	Quartz sandstone, interbedded with red hematite shale, some feldspar grains, very altered to white kaolin material.	
	2197	2198	Arkose, red, coarse grained.	
	2198	--		Precambrian

Appendix 2 - continued

Well number	Footage From-To	Description	Formation
0-62	-- 1125	Dolomite, gray, argillaceous, very glauconitic, small wavy shale bands throughout.	Bonneterre
	1125 --	Quartz sandstone, white, coarse grained, directly at contact gradually becoming fine to medium grained down hole, kaolin in pore spaces.	Lamotte
0-63	-- 1077	Dolomite, gray, trace of shale, glauconitic, few small wavy shale partings.	Bonneterre
	1077 1349	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces, dirty zones at 1319 and 1340-1349.	Lamotte
	1349 1374	Quartz sandstone, verigated hematite stain, dirty.	
	1374 1390	Quartz sandstone, strong hematite stain, dirty.	
	1390 1391	Arkose, red, pebble conglomerate.	
	1391 --		Precambrian
0-65	1035 1094	Alternating dolomitic shales and quartz sandstones with shale flecks throughout, zones from 1 to $1\frac{1}{2}$ feet thick, mainly shale at top of sequence and sand toward base. At base, shale is very contorted and has the appearance of slimy structure. Some samples show vertical structure with sand truncations. Presence of many "shear planes."	Bonneterre
	1094 --	Quartz sandstone, white, fine to medium grained, trace of kaolin in pore spaces.	Lamotte

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
0-66	--	1079	Dolomite, gray, argillaceous, glauconitic.	Bonneterre
	1079	--	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-67	--	1337	Dolomite, gray, very argillaceous, glauconitic, many small wavy shale partings.	Bonneterre
	1337	--	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-68	2142	2150	Dolomite, gray, dirty, arenaceous.	Bonneterre
	2150	2220	Quartz sandstone, white, fine to medium grained, alternating open and kaolin filled pore spaces, become kaolin filled pore spaces down hole.	Lamotte
	2220	2264	Quartz sandstone conglomerate, white, kaolin in pore spaces.	
	2264	2270	Arkose, feldspar, grains very badly weathered and kaolinized.	
	2270	--		Precambrian
0-70	--	1276	Dolomite, gray, very arenaceous, wavy shale partings.	Bonneterre
	1276	--	Quartz sandstone, white, fine to medium grained, sub-rounded, kaolin in pore spaces.	Lamotte
0-71	--	1076	Dolomite, gray, trace shale, glauconitic, few small wavy shale partings, black, pyritic, shale at contact.	Bonneterre

Appendix 2 - continued

Well number	Footage From-To	Description	Formation
0-71	1076 --	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-72	-- 1126	Quartz sandstone, gray, fine to medium grained, with much dolomite, gray, trace glauconite, trace shale few small wavy shale partings.	Bonneterre
	1126 --	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
0-73	-- 1138	Quartz sandstone, gray, fine to medium grained, with dolomite, gray, trace glauconite.	Bonneterre
	1138 1152	Quartz sandstone, white, fine to medium grained, kaolin in pore spaces.	Lamotte
	1152 1252	Quartz sandstone, buff to yellow, argillaceous, arenaceous, poor sorting, some coarse particles which appear to be feldspar fragments which have been completely kaolinized.	
	1252 1258	Quartz siltstone, gray to black, argillaceous.	
	1258 1264	Subarkose, conglomerate, shale, distorted, variegated hematite stain throughout.	
	1264 1268	Arkose? Appears like very badly weathered regolith.	
	1268 --		Precambrian

Appendix 2 - continued

Well number	Footage From-To		Description	Formation
0-74	--	993	Dolomite, gray, argillaceous, arenaceous, slightly glauconitic.	Bonneterre
	993	--	Quartz sandstone, white, medium to coarse grained, subrounded, kaolin in pore spaces.	Lamotte
0-75	--	1135	Quartz sandstone, gray, dirty, very dolomitic, glauconitic.	Bonneterre
	1135	1300	Quartz sandstone, white, fine to medium grained, subrounded, kaolin in pore spaces.	Lamotte
	1300	1417	Quartz sandstone, buff to white, argillaceous, arenaceous, becoming more so down hole from 1399-1402, very dirty material, black.	
	1417	1431	Quartz sandstone, red hematite stain throughout, dirty.	
	1431	1443	Subarkose becoming more arkosic down hole, fine grains with few small pebbles scattered throughout.	
	1443	--		Precambrian

APPENDIX 3

MATHEMATICAL PROCEDURES EMPLOYED IN TREND SURFACE ANALYSIS

A. Least Squares Fitting of Trend Surface Values

The fitting of a mathematical surface to existing data values employs the method of least squares fitting of data. This is best illustrated by considering the case of a straight line.

The equation for a straight line can be written as:

$$Y = a + bX \tag{3-1}$$

where X is an independent variable which it is assumed can be selected without error and Y is a dependent variable corresponding to each X value. The value a is the intercept of the line and b is the slope.

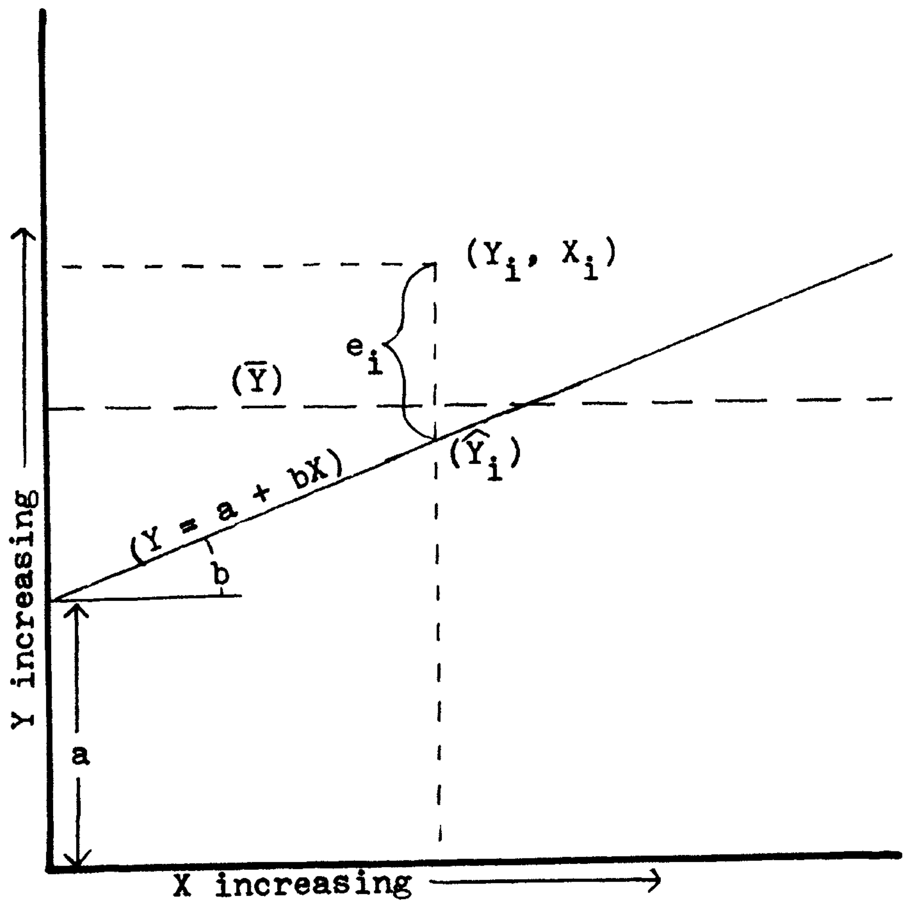
If a series of measurements are then taken, $\hat{Y}_i$, the expected value of Y_i at a given value of X_i, can be defined as:

$$Y_i = \hat{Y}_i + e_i \tag{3-2}$$

and

$$\hat{Y}_i = \hat{a} + \hat{b}X_i \tag{3-3}$$

where e_i is a measure of error, that is, how much $\hat{Y}_i$ departs from Y_i. The errors, e_i, are assumed to be random uncorrelated variables with a mean of zero and a variance of σ^2. The values $\hat{a}$ and $\hat{b}$ are estimators of the true a and b. Figure 17



$(Y_i - \hat{Y}_i)$ = Deviations from regression

$(\hat{Y}_i - \bar{Y})$ = Deviations due to regression

Y = Mean

Y_i = Observed value of Y at X_i

$\hat{Y}_i$ = Expected value of Y at X_i

a = Value of Y when X equals zero

b = Slope of regression line

Figure 17. Relationship between an observation and the simple linear model.

illustrates these relationships.

Substituting Y_i for $\widehat{Y_i}$ in equation 3-3 yields:

$$Y_i = \hat{a} + \hat{b}X_i + e_i \qquad 3\text{-}4$$

and rearranging equation 3-4:

$$e_i = Y_i - (\hat{a} + \hat{b}X_i) \qquad 3\text{-}5$$

The line of best fit is, by definition, that line defined by the coefficients obtained when the squared value of e_i is the least possible value. By squaring equation 3-5:

$$e_i^{\,2} = (Y_i - \hat{a} - \hat{b}X_i)^2 \qquad 3\text{-}6$$

and minimizing this squared equation the best estimator $\hat{a}$ of a and $\hat{b}$ of b may be determined for the least squares solution.

To minimize, the following procedure is followed:

let $$Q = \Sigma\ (Y_i - \hat{a} - \hat{b}X_i)^2 \qquad 3\text{-}7$$

solve the partial differentials of Q for $\hat{a}$ and $\hat{b}$ and then equate these derivations to zero:

$$\frac{\partial Q}{\partial \hat{a}} = -2\ \Sigma\ (Y_i - \hat{a} - \hat{b}X_i) = 0 \qquad 3\text{-}8$$

$$\frac{\partial Q}{\partial \hat{b}} = -2\ \Sigma\ X_i\ (Y_i - \hat{a} - \hat{b}X_i) = 0 \qquad 3\text{-}9$$

These procedures yield the normal equations 3-10 and 3-11:

$$\sum_{i=1}^{n} Y_i = n\hat{a} + \hat{b}\sum_{i=1}^{n} X_i \qquad 3\text{-}10$$

$$\sum_{i=1}^{n} X_i Y_i = \hat{a}\sum_{i=1}^{n} X_i + \hat{b}\sum_{i=1}^{n} X_i^{\,2} \qquad 3\text{-}11$$

The solution of these simultaneous equations yields the best estimators of $\hat{a}$ and $\hat{b}$ which when substituted into equation 3-3 yield $\widehat{Y_i}$.

The equations above illustrate the least squares method of selecting the best regression equation. It has been assumed that a linear fit was desired. However, it may be that this model does not satisfactorily explain the natural phenomenon and more variables are needed in the regression equation. In the search for a model which will satisfactorily explain the natural phenomenon it is possible to increase the degree of the regression equation, increase the number of independent variables, or do both. A trend surface equation contains two independent variables and the degree of the equation is allowed to vary as the investigator deems necessary. The procedures required to solve these equations are analogous to the procedures previously described.

The simplest trend surface is a plane. The relationship between X and Y, the map coordinates, and Z the measured value at the map coordinates can be described by the following equation:

$$Z = a + bX + cY \qquad 3\text{-}12$$

A trend surface is named according to the highest power term found in the equation. Equation 3-12 is a first order equation. More complex higher order surfaces are obtained by the addition of the X and Y terms and their cross products raised to the appropriate power.

The terms in the various order trend surface equations are shown in Table VI.

B. Residuals

If e_i from equation 3-6 were minimized to zero all observable points would be located exactly on the line of least squares. With natural data, however, a perfect fit as this will almost never occur and the observed data values will fall either above, on, or below the best fitting line or surface. The difference between the computed equation and the observed value is called the residual. The residual is defined as the difference $e_i = Y_i - \widehat{Y}_i$, where Y_i is the observed value and $\widehat{Y}_i$ is the corresponding fitted value at the same value of X_i.

TABLE VI

COMPONENTS OF VARIOUS DEGREE TREND SURFACES

Degree of surface	Dependent variable	Components
1st	Z	$a + bX + cY$
2nd	Z	$a + bX + cY + dX^2 + eXY + fY^2$
3rd	Z	$\ldots + gX^3 + hX^2Y + iXY^2 + jY^3$
4th	Z	$\ldots + kX^4 + lX^3Y + mXY^3 + nY^4$
5th	Z	$\ldots + oX^5 + pX^4Y + qX^3Y^2 + rX^2Y^3 + sXY^4 + tY^5$
6th	Z	$\ldots + uX^6 + vX^5Y + wX^4Y^2 + aaX^3Y^3 + bbX^2Y^4 + ccXY^5 + ddY^6$
7th	Z	$\ldots + eeX^7 + ffX^6Y + ggX^5Y^2 + hhX^4Y^3 + iiX^3Y^4 + jjX^2Y^5 + kkXY^6 + llY^7$

With geological data, large scale regional features normally will be shown by the trend surface whereas small local features will be defined by the residuals. Interpretation of the residuals from trend surface analysis is therefore a method which removes the masking effect of large scale regional features and emphasizes the small local features which are often more significant in geological exploration.

Special attention, however, must be paid to outliers. Outliers are defined as residual values which are many times greater than the other residuals. An outlier may be the result of a procedural or gross error in which case it should be discarded. It is possible, however, that due to an unusual combination of circumstances the outlier is providing vital information which none of the other data points can.

C. Testing the Trend Surface

Before any inferences can be drawn from the trend surface, it is necessary to define 'how good' the data agrees with the trend surface. This can be accomplished in several ways.

1. Goodness of fit.--The goodness of fit of a trend surface may be expressed as a percentage reduction in the total sum of squares. This is given in the expression 3-13:

$$\text{Goodness of fit} = 100 \times \frac{\sum_{i=1}^{n} \hat{Y}_i^{\,2} - \frac{(\sum_{i=1}^{n} \hat{Y}_i)^2}{N}}{\sum_{i=1}^{n} Y_i^{\,2} - \frac{(\sum_{i=1}^{n} Y_i)^2}{N}} \qquad 3\text{-}13$$

where $\hat{Y}_i$ = Values on the trend surface at the location of the data points

Y_i = Observed data values

N = Number of data values

A perfect fit of the trend function to the data points would yield a value of 100 per cent. When the goodness of fit is high, most often the variation present in the data is represented by trend functions. A low goodness of fit is not necessarily bad, but interpretation of the trend surface must take this into account.

2. The correlation coefficient.--The sum of squares about the mean, $(Y_i - \overline{Y})^2$, is equal to the sum of squares about regression, $(Y_i - \widehat{Y}_i)^2$, plus the sum of squares due to regression, $(\widehat{Y}_i - \overline{Y})^2$. Stated in other terms, the sum of squares about the true mean is equal to the sum of squares from the residuals plus the sum of squares from the regression equation. This equation can be written:

$$\Sigma\ (Y_i - \overline{Y})^2 = \Sigma\ (Y_i - \widehat{Y}_i)^2 + \Sigma\ (\widehat{Y}_i - \overline{Y})^2 \qquad 3\text{-}14$$

The ratio of the total variation to the explained variation is called the coefficient of determination, r^2. This equation can be obtained from equation 3-14:

$$r^2 = \frac{\Sigma\ (\widehat{Y}_i - \overline{Y})^2}{\Sigma\ (Y_i - \overline{Y})^2} \qquad 3\text{-}15$$

If none of the variation is accounted for by the regression this ratio is equal to zero. If all the variation is explained, the ratio is one. The correlation coefficient is the square root of the coefficient of determination and varies from -1 to +1.

$$r = \sqrt{r^2} \qquad 3\text{-}16$$

This is a dimensionless quantity as it does not depend on the units employed.

3. Analysis of variance of the regression equation.--Any sum of squares derived from a compilation of data has a defining parameter referred to as the degrees of freedom. This then indicates how many items of information were involved in determining its sum of squares. If the sum of squares due to regression and the sum of squares about regression are both divided by their degrees of freedom the mean squares of each is obtained. If the mean square due to regression is divided by the mean square about regression, a calculated F value is obtained. This value is an indication of the validity of the regression equation and can be compared with values obtained from an F-table to determine the validity of the regression equation.

In applying analysis of variance as a test of the regression equation, the hypothesis being tested is that the coefficients of the regression components are equal to zero, i.e. there is no regression. If the computed value of F exceeds the value of F from the F-table, this hypothesis must be rejected and the alternate hypothesis that the coefficients of the regression components are not equal to zero is accepted. The relationship between these different variables can be seen summarized in Table VII.

TABLE VII

COMPONENTS FOR ANALYSIS OF VARIANCE

OF THE REGRESSION EQUATION

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Ratio of mean squares (F ratio)
Due to regression	M	$S_t = \Sigma(\hat{Y}_i - \bar{Y})^2$	$MS_1 = \frac{S_t}{M}$	$F = \frac{MS_1}{MS_2}$
About regression	N-M-1	$S_d = \Sigma(Y_i - \hat{Y}_i)^2$	$MS_2 = \frac{S_d}{(N-M-1)}$	
Total	N-1	$S_{t1} = \Sigma(Y_i - \bar{Y})^2$		

where M = number of terms in trend component

N = number of data points

S_t = sum of squares due to regression

S_d = sum of squares about regression

S_{t1} = sum of squares due to total variation

$\hat{Y}_i$ = value predicted by trend function

Y_i = observed data value

$\bar{Y}$ = mean of observed data value

MS_1 = mean square associated with regression

MS_2 = mean square associated with deviations

APPENDIX 4

DESCRIPTION OF SELECTED WELLS IN LAMOTTE SANDSTONE

The following is a discussion of wells which best typified the character of the Lamotte throughout the study area. Figure 18 gives the location of these wells.

A. Viburnum Trend Area:
Wells 0-29 to 0-67

This series of samples was taken from wells drilled on a generally north-south band on the west side of the St. Francois Mountains (Fig. 18). While these wells did not penetrate the full Lamotte section, they do provide a valuable insight into the general characteristic of the upper Lamotte and the Lamotte-Bonneterre contact.

The upper Lamotte in this area is generally a buff to white, fine to medium grained, well rounded quartz sandstone. The very upper Lamotte (Unit A) is normally a very poorly cemented, very porous sandstone. Below this unit there is another unit (Unit B) which is basically the same except that a white kaolinitic material fills the pore space.

In known basinal areas, Unit A is absent and Unit B grades directly into lower Bonneterre (see Appendix 2, Well 0-41). As known Precambrian highs are approached, Unit A appears and a thin black pyritic shale is found at the Lamotte-

Figure 18. Index map illustrating location of well logs.

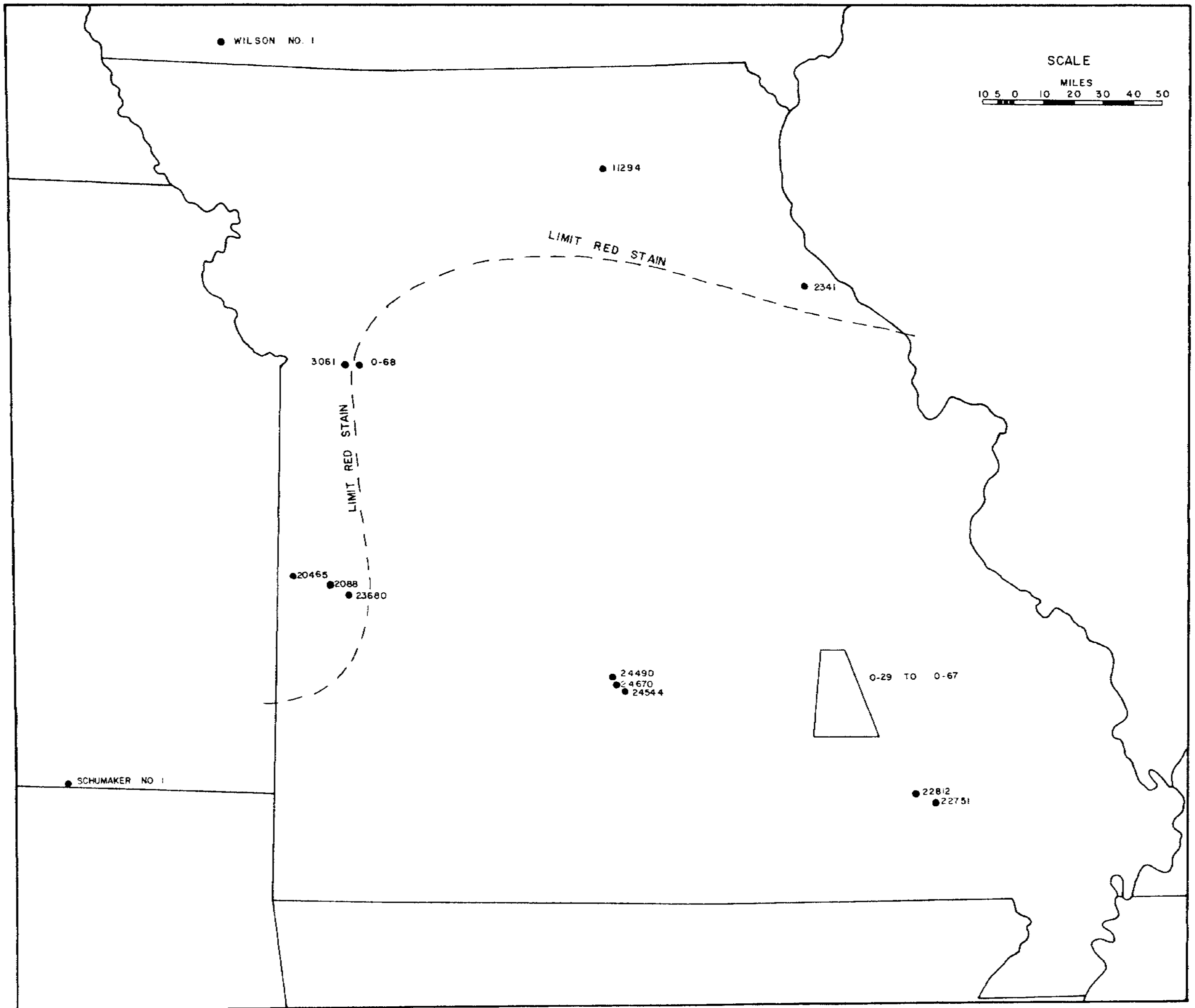

WILSON NO. 1
SCALE
MILES
10 5 0 10 20 30 40 50
11294
LIMIT RED STAIN
2341
3061
0-68
LIMIT RED STAIN
20465
2088
23680
24490
24670
24544
0-29 TO 0-67
SCHUMAKER NO 1
22812
22751

Figure 18.

Bonneterre contact (see Appendix 2, Wells 0-31 and 0-35). The basal Bonneterre also exhibits a facies change from known basinal areas to areas of known Precambrian highs. Near and above known Precambrian highs, the basal Bonneterre is a dolomitic quartz sandstone, gray to buff and well rounded (see Appendix 2, Well 0-30). Basinward the lower Bonneterre grades first into a sandy, slightly glauconitic dolomite (see Appendix 2, Well 0-36) then into an argillaceous glauconitic dolomite (see Appendix 2, Wells 0-29 and 0-32) to a relatively clean pure dolomite (see Appendix 2, Wells 0-41 and 0-49). The relationship between the various facies of the Lamotte and lower Bonneterre are illustrated in Figure 19, a composite section drawn from Wells 0-29 to 0-67.

Well 0-65 shows an unusual Bonneterre-Lamotte contact. This well lies just north of a small Precambrian knob upon which there is no Lamotte (Ruskell, Personal communications, 1971). Instead of a vertical change from sand to dolomite this well has alternating sands and shales, the sands appearing to be reworked. Also in this same general area are a series of wells which penetrated a section in which typical Lamotte is overlain by what appears to be a typical basal arkose (Ruskell, Personal communications, 1971). It would therefore appear that there was a change in energy of deposition between Lamotte and Bonneterre depositional periods and that in this locale there is an unconformity between the Lamotte and Bonneterre.

Figure 19. Composite cross section of Lamotte-Bonneterre stratigraphy on west flank of Ozark Dome. Compiled from Wells 0-29 to 0-67.

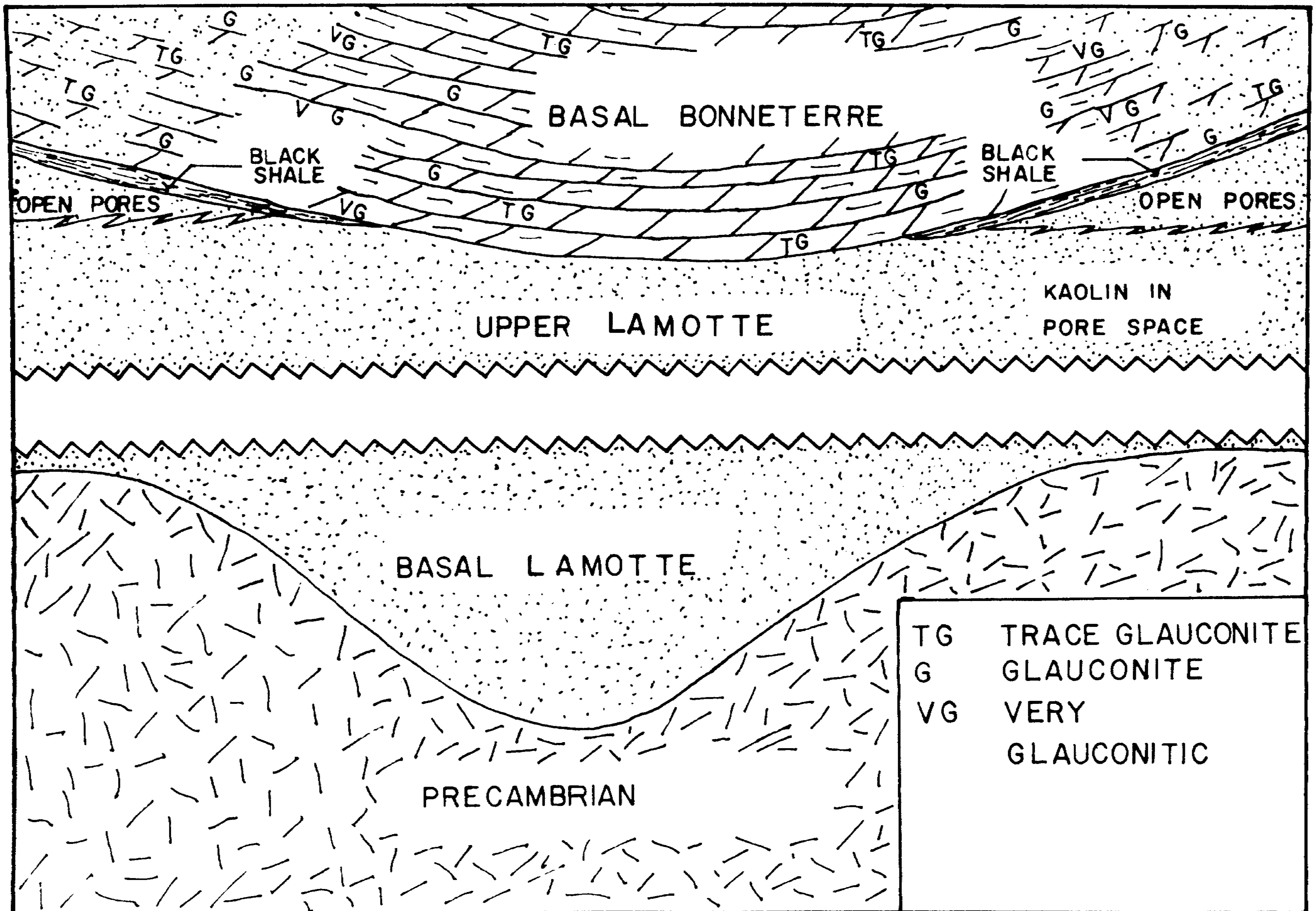

BASAL BONNETERRE
BLACK SHALE
OPEN PORES
BLACK SHALE
OPEN PORES
UPPER LAMOTTE
KAOLIN IN PORE SPACE
BASAL LAMOTTE
PRECAMBRIAN
TG TRACE GLAUCONITE
G GLAUCONITE
VG VERY GLAUCONITIC

Figure 19.

B. Laclede County: Wells
22490, 24670 and 24544

The wells in this area show clearly the general characteristics which have been observed in the Lamotte and Lamotte-Bonneterre contact throughout the study area (see Appendix 2, Wells 22490, 24670 and 24544).

The lower Bonneterre exhibits the same general characteristics as have been noted in the area of the Viburnum Trend. Near the Precambrian high this zone is a fine, well rounded, gray sandstone. As this zone is traced basinward, it becomes more dolomitic and glauconitic. It is quite easy to trace mentally the lower Bonneterre basinward until the change from sand to dolomite becomes complete.

Five easily discernible units can be recognized in the Lamotte. The upper two units are white to buff, fine-to medium grained sandstone, the upper (Unit A) with open pore spaces and the lower (Unit B) with kaolin in the pore spaces. Directly below these two buff sand units, there is a subarkosic unit (Unit C) characterized by the strong hematite stain covering all the particles. This unit appears to have a facies relationship with the fourth sand unit (Unit D), a buff to gray subarkosic sand. This lower buff sand is only found away from the known Precambrian knobs.

The lowermost Lamotte unit is a true basal arkose (Unit E) believed to be formed from the washing off and reworking of the Precambrian regolith from the Precambrian knobs. In this area this unit is only found in the two most basinal

Figure 20. Cross section of Lamotte-Bonneterre stratigraphy, Laclede County, Missouri. No horizontal scale. Approximate vertical scale 1 inch = 80 feet.

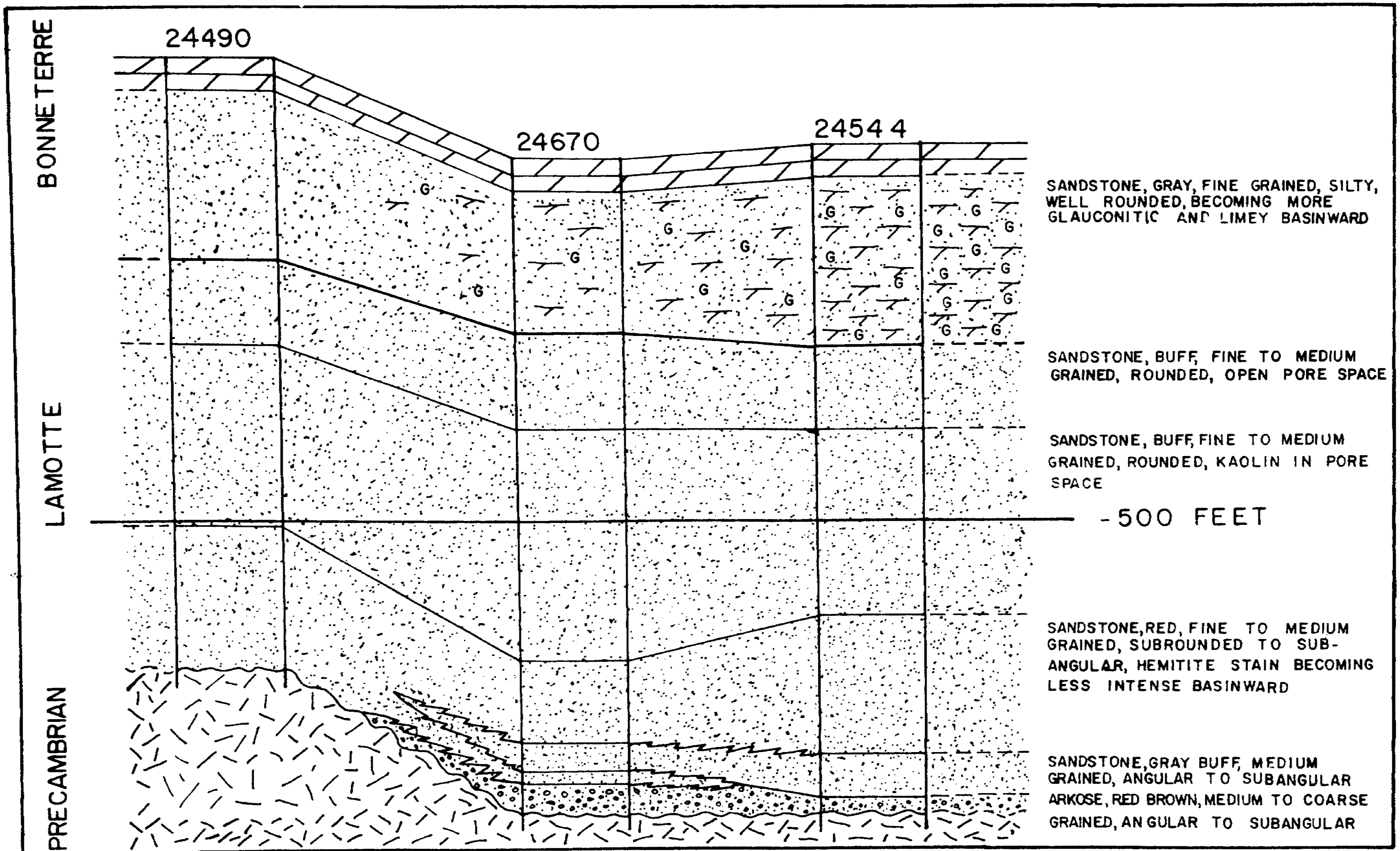

BONNETERRE
LAMOTTE
PRECAMBRIAN
24490
24670
2454 4
-500 FEET
SANDSTONE, GRAY, FINE GRAINED, SILTY, WELL ROUNDED, BECOMING MORE GLAUCONITIC AND LIMEY BASINWARD
SANDSTONE, BUFF, FINE TO MEDIUM GRAINED, ROUNDED, OPEN PORE SPACE
SANDSTONE, BUFF, FINE TO MEDIUM GRAINED, ROUNDED, KAOLIN IN PORE SPACE
SANDSTONE, RED, FINE TO MEDIUM GRAINED, SUBROUNDED TO SUB-ANGULAR, HEMITITE STAIN BECOMING LESS INTENSE BASINWARD
SANDSTONE, GRAY BUFF, MEDIUM GRAINED, ANGULAR TO SUBANGULAR
ARKOSE, RED BROWN, MEDIUM TO COARSE GRAINED, ANGULAR TO SUBANGULAR

Figure 20.

holes.

The relationship of these units of the Lamotte and the Lamotte-Bonneterre contact is shown in Figure 20.

C. Jackson County: Well 0-68

The upper Lamotte in this area is generally the same as the upper Lamotte found in other areas throughout the state. Both Unit A and Unit B are present along with a zone separating the two in which the two sand types are interbedded. Below Unit B is a gray quartz conglomerate containing quartz pebbles up to one inch in diameter. The matrix is composed of fine quartz sand and kaolinitic material. This zone contains highly altered (kaolinized) feldspar grains. This zone, Unit D, is directly below Unit B as no Unit C, the red hematite-stained zone, is present.

Unit E, the basal arkose, contains feldspar grains, very slightly altered, which appear identical to the feldspar grains found in the underlying Precambrian. It is possible, therefore, to observe feldspar grains in all states of alteration up to the base of Unit B. The kaolinitic material found in the pore space of the Unit B sandstone appears identical to the material found on the edges of the altered feldspar grains. It, therefore, appears that the kaolinitic material noted in the Lamotte throughout the state was derived from weathering of the underlying Precambrian and reworking and dispersion of this material throughout the Lamotte.

This well has no zone of hematite staining and shows no red stains on the individual quartz grains.

D. Page County, Iowa:
Wilson #1

Wilson #1 is located in the extension of the Keeweenawan Basin as outlined by Snyder (1968a). This well has penetrated more than 1,700 feet of a Precambrian clastic material which is overlain by a 15 foot section which has been identified as Mt. Simon. According to Koch (personal communication, 1971) the break between the two is marked by an unconformity and the red clastic material has been tentatively identified as being equivalent to either the Hinckley Sandstone or the Fond du Lac Sandstone of upper Keeweenawan age. This section is a dirty quartzose material which perhaps can be best characteriaed by the red hematite staining throughout and by the fact that the individual grains have a red stain. Several of the northern Lamotte wells have a section in which the individual quartz grains have a red stain.

Wells 2341, 11294, 3061, 20465, 2088, and 23680 are the most southerly wells in which the Lamotte contains quartz grains which are stained (Fig. 18). The break from red stained to nonstained quartz grains is very abrupt as Well 3061 in Jackson County shows the stain on the individual grains while 0-68, 6 miles away does not. As this stain is best developed to the north and disappears to the south, it would seem that the source area for the red-stained material must be to the north. It can further be implied that the source for part of the Lamotte sandstone would be the Precambrian clastics of the Keeweenawan Basin extension.

E. Montgomery County,
Kansas: Schumaker #1

No samples of the Lamotte in Kansas were studied. However, several well logs were examined to determine the general characteristics of the formation. Schumaker #1 portrays the characteristics which were noted in this examination.

TABLE VIII

DESCRIPTION OF PART OF SCHUMAKER #1

2640-2645	White, coarse grained, subrounded dolomite sandstone.
2645-2730	Gray, medium crystalline to rhombic, sandy, glauconitic dolomite.
2730-2780	Gray, fine to very coarse grained, subangular to subrounded, frosted, profusely glauconitic, dolomitic sandstone.
2780-2806	Sandstone, very coarse grained, (almost conglomerate), shaly, pyritic and non-dolomitic.
2806-2837	Gray and pink granite, top 4 or 5 feet deeply weathered.

In this well, the top of the Lamotte had been chosen at 2,730 feet. The description of the interval from 2,730 to 2,780 is quite similar to the basal Bonneterre in most of the state of Missouri (see Laclede County) and would seem as though this interval should be placed in the basal Bonneterre rather than Lamotte.

F. Wayne County: Wells
22812 and 22751

In the wells studied in Wayne County a strong change becomes apparent in the basal Paleozoic. The wells in this area generally show no recognizable Lamotte. Well 22812 (Fig.

18) would appear to be a typical example. The lowermost Paleozoic in this well is a true basal arkose. The material above this arkose varies from an argillaceous calcareous sandstone to an arenaceous calcareous shale. In the 300+ foot zone from the top of the Bonneterre to the top of the Precambrian it is impossible to pick a definable Lamotte-Bonneterre contact. In other wells in the area the section will vary but the same general characteristics are apparent. Well 22751 (Fig. 18), for example, has a 450+ foot section from the top of the Bonneterre to the Precambrian in which the lower 50 feet bear some resemblance to recognizable Lamotte. The section defined as Bonneterre shows considerable thickening in southeastern Missouri and this has been interpreted to show a paleoslope in the direction of the Mississippi Embayment (Grohskopf, 1955). In northwestern Tennessee a well was drilled which penetrated a lower Paleozoic section thought to be Lamotte equivalent (Statler, personal communications, 1971). The part of the section which would correspond to the Lamotte is entirely siltstone. Grohskopf (1955) examined this section and described it as quartzlike, dark gray, extremely fine grained, hard and compact and somewhat calcareous and dolomitic. The main conclusion to be noted from this discussion is that the basal Paleozoic section appears to be undergoing a reduction in grain size with a corresponding increase in the percentage of nonclastic material deposited.

Most work to date on the Lamotte accepts the existence of a generally northern source for the Lamotte. In addition, Snyder (1968a, 1968b) has described an east-west continental divide which would pass through the St. Francois Mountains. The character of the basal Paleozoic sediments in Wayne County suggests a deeper water environment than the normal Lamotte required. With the generally northern source for clastic material and an early Paleozoic continental divide, it would appear that during the Lamotte deposition little clastic material was available in this area and that which was available was unable to pass over the continental divide. The extreme thickening of the Bonneterre is probably the combination of a paleoslope into the Mississippi Embayment area and partially the result of a facies equivalent of typical Lamotte being defined in the lower Paleozoic in this area as Bonneterre.

During later geological eras this region has normally been a strong negative area. It would appear from the information to date that the character of the basal Paleozoic would also indicate that this area was a strong negative area during the early Paleozoic and that during the early Paleozoic this area was already showing the general characteristics for which it would later be noted.

APPENDIX 5

COMPARISON OF LAMOTTE THICKNESS WITH RESIDUALS FROM TREND SURFACE ANALYSIS OF PRECAMBRIAN SURFACE

Regression analysis was carried out in an attempt to compare the thickness of the Lamotte Formation with residuals from the trend surface analysis of the Precambrian surface.

The thickness of the Lamotte is directly related to the relief of the Precambrian surface. Ideally, a thick Lamotte sequence was built up in the deeper valleys and basins where little or no Lamotte was deposited on the high Precambrian knobs. This relationship breaks down during the latter state of Lamotte deposition when, due to a reduction in the amount of clastics from the source area, more non-clastic carbonate material was being deposited in the basinal areas. This carbonate sequence would now be included with the Bonneterre Formation. Therefore, the two main factors contributing to thickness variations in the Lamotte would be the original topography of the Precambrian surface and the amount of clastic material being furnished from the source area.

Since the main factors contributing to the residuals are the large scale regional variation not removed by the trend surface along with original relief on the Precambrian surface and small scale structural disturbances, it is apparent that one factor common to both the residuals and thickness of the Lamotte is the original relief of the Precambrian surface. The results of regression analysis comparing Lamotte thickness with the residuals from the third and sixth order trend surfaces are shown below:

TABLE IX

COMPARISON OF LAMOTTE THICKNESS WITH RESIDUALS FROM TREND SURFACE ANALYSIS

Order Equation	Correlation Coefficient	Coefficient of Determination	T Value	F-Ratio
3	.5501	.3026	-2.124	4.515
6	.6734	.4535	-6.091	37.161

Using the coefficient of determination as a measure of the degree of association between the variables shows that in the third order surface, 30 per cent of the variation is common to both variables where as for the sixth order surface, 45 per cent of the variation is common to both variables, or 70 per cent of the variation is unexplained in the third order equation and 55 per cent of the variation is unexplained in the sixth order equation. The unexplained variation in the regression analysis would be mainly contributed by a change in rate of clastic material from the source area, the small scale structural disturbance or faults, and the regional trend which has not been removed by the trend surface. As the sixth order surface is a better approximation of the Precambrian surface than the third order surface, it follows that this is the major reason for the difference in amount of unexplained variation as more of the regional trend has been removed from the sixth order residuals. Since the thickness variation due to facies changes resulting from changes in the amount of clastic material available and post depositional faulting would tend to decrease the correlation between the two variables, it follows that at least 30 per cent of the third order residual map and 45 per cent of the sixth order map is a direct indication of the original relief on the Precambrian surface.

In summary, the variations in thickness of the Lamotte are directly related to the preexisting topographic variations of the Precambrian surface. The correlation between the residuals from trend surface analysis of the Precambrian surface and Lamotte isopach data proves that the residuals from the Precambrian trend surface do, in part, portray original topographic variations on the Precambrian surface.